AD 629 930

GCA Technical Report 65-15-G

HIGH ALTITUDE GUN PROBES

(Development of Langmuir Probes)

FINAL REPORT

Contract No. DA-19-020-AMC-00292(R)

September 1965

A. V. Block
A. L. Kadis
L. C. Smith

GCA CORPORATION
GCA TECHNOLOGY DIVISION
Bedford, Massachusetts

Distribution of this document is unlimited.

Prepared for

BALLISTIC RESEARCH LABORATORIES
Aberdeen Proving Ground, Maryland

Destroy this report when it is no longer needed.
Do not return it to the originator.

The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

GCA Technical Report 65-15-G

HIGH ALTITUDE GUN PROBES

(Development of Langmuir Probes)

FINAL REPORT

Contract No. DA-19-020-AMC-00292(R)

September 1965

A. V. Block
A. L. Kadis
L. G. Smith

Distribution of this document is unlimited.

GCA CORPORATION
GCA TECHNOLOGY DIVISION
Bedford, Massachusetts

Prepared for

BALLISTIC RESEARCH LABORATORIES
Aberdeen Proving Ground, Maryland

This work was supported in part by the Defense Atomic
Support Agency under Task 07.512T, MIPR 634-65.

TABLE OF CONTENTS

SECTION 1

INTRODUCTION

This final report describes a program to develop an instrument capable of measuring electron density in the 50 to 160 kilometer altitude region and capable of surviving a 60,000 "G" shock encountered during launch from a cannon. This report is in two parts: The first describes various techniques and instruments capable of measuring electron density in this altitude region. The second section describes the design techniques as well as flight results from these probes. Both dc and ac Langmuir probes were chosen as the best instruments for fulfilling the system requirements.

During this program, a sizable effort was devoted to evaluating components and construction techniques in order to ensure survival at launches up to 60,000 "G's". Actual testing of these devices was performed at Aberdeen Proving Ground, Maryland, by horizontally firing the equipments from a 5-inch cannon into a block of lead and adjusting the deceleration to conform to the required "G" levels.

Vertical launches of one dc-probe (BRUTUS) and two ac-probes (IRE and JANUS) were made during the May and June 1965 HARP firings at Barbados, British West Indies. Electron density profiles were obtained for the 50 to 120 kilometer altitude region. Other probes have been built and are expected to be launched within the next 6-month period.

SECTION 2

THEORETICAL CONSIDERATIONS

2.1 THE LOWER IONOSPHERE

2.1.1 General. The properties of the atmosphere in the height range 50 to 160 km are given in Table 1. This data is taken from the 1959 ARDC Model Atmosphere and refers only to the neutral gas. The reduction in molecular weight above 90 km is caused by dissociation of molecular oxygen. Recent rocket measurements of composition[(1)] indicate greater dissociation of oxygen giving lower values of the molecular weight above 90 km.

The atmosphere is only very slightly ionized in this low altitude region; at 160 km the fraction ionized is about 10^{-5} and the fraction is smaller at lower altitudes. The ionizing radiation above 75 km is mainly solar uv and x-radiation augmented at high latitudes by corpuscular radiation. Below 75 km cosmic rays are believed to be the principal ionizing flux in the normal ionosphere.

The electron density in the lower ionosphere shows great variation from day to night and from quiet to disturbed conditions.

2.1.2 D Region. The principal feature distinguishing the D region from the adjacent regions is the ratio of negative ion density to electron density, usually denoted by λ. In the higher regions, i.e., above 90 km the negative ion density is negligible while in the atmosphere below 50 km the electron density is negligible. Thus in this region a great dynamic range in both electron and negative ion densities is encountered. Current theories of the region

TABLE 1

PROPERTIES OF THE 1959 ARDC MODEL ATMOSPHERE IN THE D AND E REGIONS OF THE IONOSPHERE

Height km	Temperature ^{o}K	Molecular Weight	Scale Height km	Number Density cm^{-3}	Particle Speed $cm\ sec^{-1}$	Collision Frequency sec^{-1}	Mean Free Path cm
50	282.66	28.966	8.4041	2.2519 (16)	4.5454 (4)	6.0587 (6)	7.5023 (-3)
60	253.68	28.966	7.5662	7.3275 (15)	4.3061	1.8677 (6)	2.3056 (-2)
70	209.59	28.966	6.2706	2.0813 (15)	3.9141	4.8217 (5)	8.1175 (-2)
80	165.7	28.97	4.972	4.410 (14)	3.480	9.082 (4)	3.831 (-1)
90	165.7	28.97	4.987	5.018 (13)	3.480	1.219 (4)	2.855 (0)
100	199.0	28.90	6.023	7.733 (12)	3.818	1.759 (3)	2.171 (1)
110	286.7	28.82	8.731	1.240 (12)	4.590	3.368 (2)	1.363 (2)
120	477.0	28.71	14.62	3.105 (11)	5.931	1.090 (2)	5.441 (2)
130	664.9	28.59	20.53	1.254 (11)	7.017	5.208 (1)	1.347 (3)
140	849.9	28.45	26.46	6.395 (10)	7.953	3.010 (1)	2.642 (3)
150	1031	28.27	32.40	3.748 (10)	8.788	1.950 (1)	4.507 (3)
160	1207	28.04	38.36	2.411 (10)	9.547 (4)	1.363 (1)	7.007 (3)

Numbers in parentheses are powers of 10.

indicated that the positive ion density (which must equal the sum of electron and negative ion densities) is roughly constant in the D region.

Available information, prior to the start of this program on the electron density in the D region, was based almost entirely on rf experiments using ground-based equipment. The most important of these are (1) propagation of very low frequency and low frequency waves, i.e., frequencies below 300 kc/sec, which is the plasma frequency for an electron density of 10^3 cm^{-3}; (2) low frequency vertical sounders (or radar); (3) partial reflection sounders, i.e., a vertical sounder in which the frequency (fixed) exceeds the plasma frequency anywhere in the region (for example, 2 Mc/sec); (4) wave interaction (cross-modulation); and (5) cosmic noise absorption (riometer).

Each of these techniques has its limitations and a complete and unambiguous profile of electron density is not obtained. However, such data does give an idea of the magnitude of the electron density and its variation with height and serves as a guide to the design of experiments. Figure 1 illustrates this variation for a quiet day, a quiet night and a disturbed day. Superimposed on these general variations with height, are important structural features, the exact nature of which cannot be determined from ground based experiments. However, it is known, for example, from partial reflection sounders, that certain heights are preferred while others are observed irregularly. Examples of quiet daytime profiles obtained recently on three rocket flights using the dc probe technique are shown in Figure 2. The variability of the profiles is evident. Another important feature which shows up in measurements of D region absorption in temperate latitudes, is that only when the quietest days are selected there is a marked dependence on solar zenith angle.

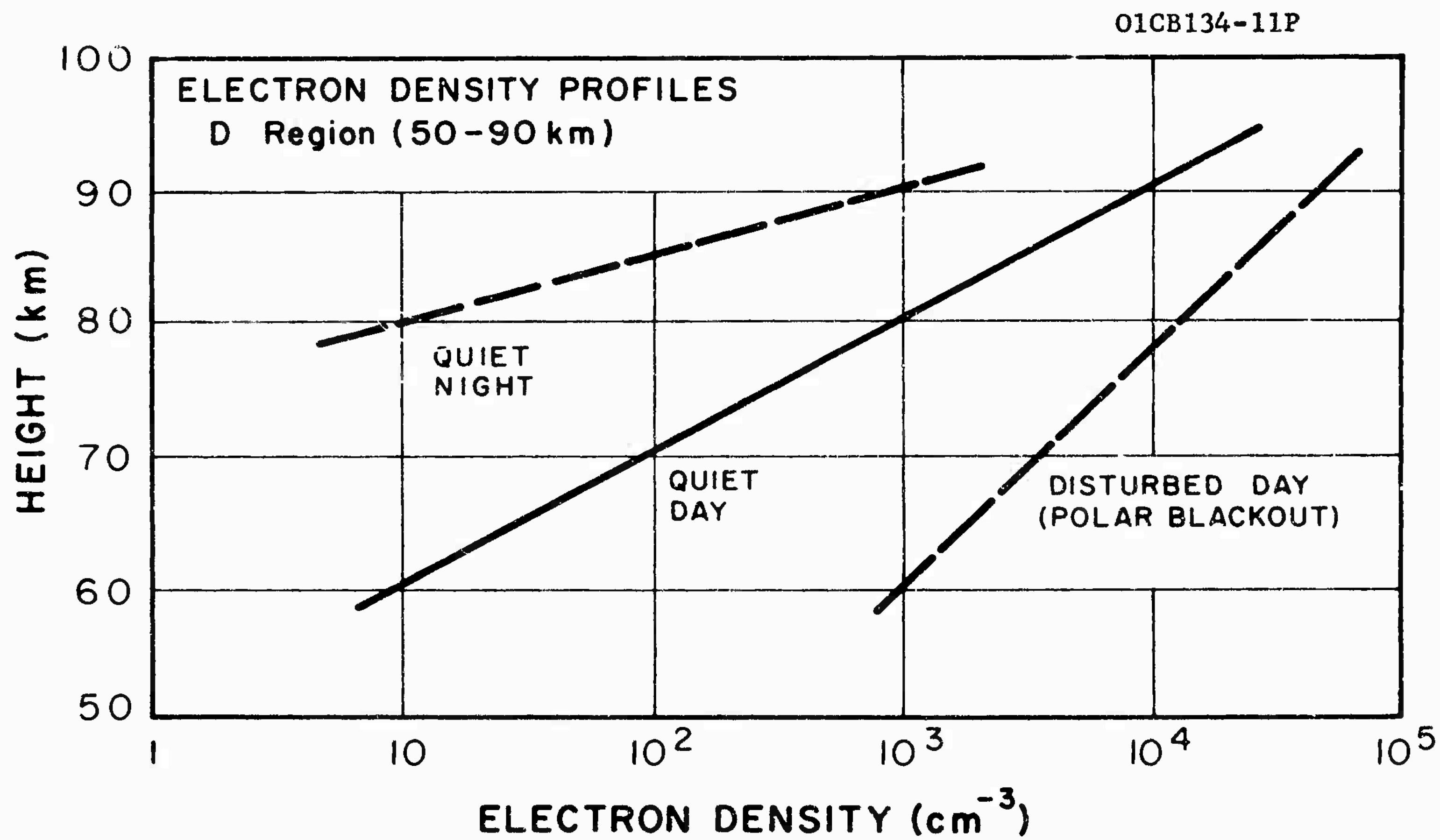


Figure 1. Electron density profiles, D-region.

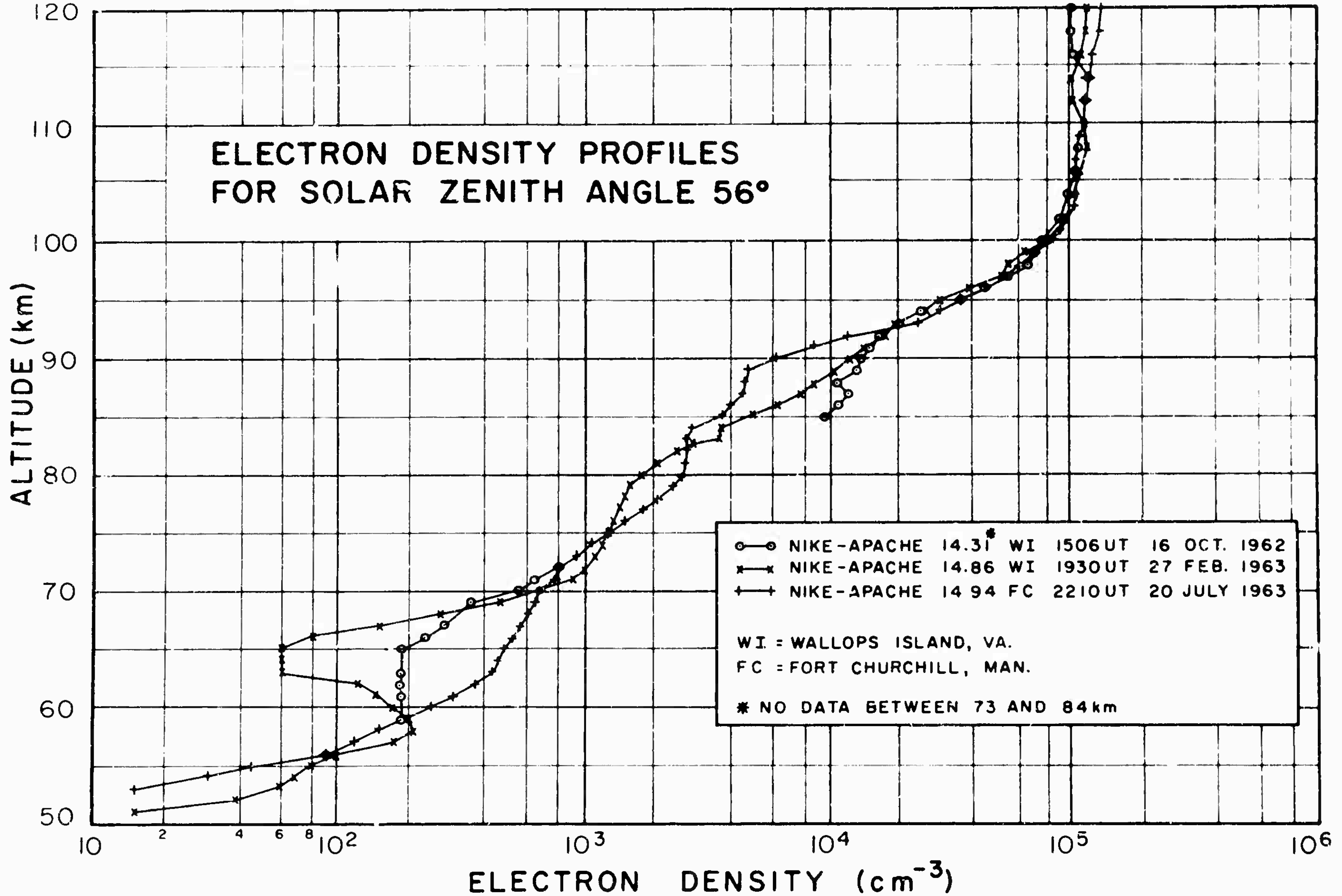


Figure 2. Electron density profiles for solar zenith angle 56^0.

The situation with respect to ion density is somewhat less satisfactory. The only guide at present to numbers to be expected comes from theoretical treatments such as that of Nicolet and Aikin[2] who predict, for a very quiet sun, a daytime value of negative ion density of 10^2 cm^{-3} at about 75 km increasing to 10^3 cm^{-3} at about 55 km. The most urgent problem in experimental studies of the D region is the development of a reliable technique for positive and negative ion density.

2.1.3 E Region. The electron density profile in the daytime E region is characterized by a flat peak at about 105 km, which gives rise to the E layer echo on an ionosonde. Above this is a shallow trough in which the electron density falls no more than 20 percent below the E layer peak value. Above about 120 km the electron density then increases more-or-less regularly to the upper boundary of the region, which is taken arbitrarily as 160 km. In principle, except for the trough region above the E layer, the electron density profile could be obtained by analysis of an ionosonde record. In practice this is not possible due to the retardation produced by the electrons of the D region as the ionosonde signal passes through, and the only significant information that is obtained from the ionosonde is the E layer critical frequency.

Studies of the variation of the critical frequency show the strong solar control of the normal daytime E layer which is probably the most regular and therefore predictable of the ionosphere. Recent rocket measurements in the nighttime E region show two characteristic differences from the daytime profile.[3,4] The nighttime E layer is irregular with pronounced horizontal stratification and, in addition, a deep trough is found above 120 km.

2.2 PROPAGATION AND PROBE TECHNIQUES

The following techniques were investigated prior to the selection of the dc probe and Langmuir probe as the instruments most suitable for use in this program.

2.2.1 Propagation Techniques.

2.2.1.1 Dispersive Doppler. The refractive index μ of an electron gas for a wave of angular frequency ω is given by

$$\mu^2 = 1 - \frac{4\pi ne^2}{m\omega^2} .$$

Thus the medium is dispersive. In the CW propagation technique as developed by Seddon[5] two harmonically related frequencies f_1 and f_2 ($f_2 > f_1$) are transmitted from the rocket to a receiving station at the ground. There the lower frequency is multiplied by the factor f_2/f_1 and mixed with the higher frequency to produce a beat frequency

$$f_b = \frac{f_2}{c} \dot{r}(1 - \mu)$$

where $\dot{r}$ is the radial velocity of the transmitter from the receiver site and μ is the refractive index in the vicinity of the rocket for the frequency f_1 (the frequency f_2 being great enough that $\mu = 1$ for that frequency). Thus measurement of the beat frequency and additional knowledge of the trajectory allow the determination of μ and hence n in the vicinity of the transmitter.

An estimate of the order of magnitude of the beat frequency can be obtained by using the following approximation for μ:

$$\mu \approx 1 - \frac{1}{2}\left(\frac{n}{n_1}\right) \qquad (n \ll n_1)$$

where n_1 is the electron density for which f_1 is the critical frequency. We may write approximately

$$f_b = \frac{1}{2} f_2 \left(\frac{\dot{r}}{c}\right)\left(\frac{n}{n_1}\right)$$

In a typical application for the D and E region

$$f_1 = 12 \text{ Mc/sec} \qquad (\text{i.e., } n_1 = 1.8 \times 10^6 \text{ cm}^{-3})$$

$$f_2 = 72 \text{ Mc/sec}$$

$$\dot{r} = 1.5 \text{ km/sec}$$

Thus $\qquad f_b \approx 10^{-4} n$ cps

The beat frequency is thus of the order of 10 cps at the peak of the E layer ($n \approx 10^5$ cm^{-3}). The difficulty of accurately measuring a small beat frequency as the rocket passes through the region limits the technique, as normally used, to electron densities greater than about 10^3 cm^{-3}. There is, however, no fundamental reason why lower frequencies should not be used and the method used to lower electron densities. For example using 1.2 and 72 Mc/sec the beat frequency is approximately $10^{-2}n$ cm^{-3}. Thus an electron density of 10 cm^{-3} could, in principle, be measured. The upper limit though would be given by the electron density n_1, i.e., 1.8×10^4 cm^{-3}.

The simple formula for refractive index given above must, in the actual ionosphere, be modified to allow for two important features. The first is the presence of the earth's magnetic field and the second is the effect of collisions of electrons with the neutral gas particles. The effect of the magnetic field is important all through the ionosphere but the effect of the collisions is largely restricted to the D region. The actual values of electron collision frequency may be calculated but is also obtained experimentally from absorption measurements as described below.

2.2.1.2 Faraday Rotation. The earth's magnetic field causes the ionosphere to become a birefringent medium. Thus a radio wave travelling through the region is split into two components (ordinary and extraordinary) which have different refractive indices. The net effect on a plane polarized wave of frequency f is to rotate the plane of polarization at a rate given by

$$\frac{d\Omega}{dh} = 2.36 \times 10^{4} f^{-2} nH \cos\theta \text{ rad/km}$$

where $H \cos\theta$ is the component of the magnetic field in gauss along the direction of propagation. For a signal transmitted to (or from) a rocket travelling vertically with velocity v the rate of rotation of the plane of polarization may be expressed as

$$\frac{d\Omega}{dt} = 4.8 \times 10^{-5} v \frac{n}{n_o} H \cos\theta \text{ rps}$$

Assuming $v = 1.5$ km/sec and $H \cos\theta = 0.5$ gauss

$$\frac{d\Omega}{dt} = 3.6 \frac{n}{n_o} \text{ rps}$$

Since the frequency of the signal must be greater than the local plasma frequency it immediately appears that the rotation to be measured is a small effect.[6] However, it has been successfully used to measure electron density in the D region.[7] It cannot be used at the magnetic equator (since $\cos\theta = 0$).

The application of the technique requires a knowledge of the spin rate of the rocket. This can be obtained with sufficient accuracy only by including auxiliary equipment, such as a magnetic or a solar aspect sensor.

2.2.1.3 Absorption. The collision of electrons with neutral gas particles removes energy from the radio wave traversing the medium. The field strength at a height h_1 in the ionosphere is reduced by the factor $\exp \int_0^{h_1} \kappa dh$ due to absorption, where κ is given by the complete magneto-ionic theory. In the simplest case

$$\kappa = \left(\frac{2\pi e^2}{Mc}\right)\frac{1}{\mu}\frac{n\nu}{\nu^2 + (\omega \pm \omega_H)^2} \quad \text{(cgs units)}$$

where μ is the refractive index and $\omega_H (= 2\pi f_H)$ is the angular gyro-frequency, f_H being about 1.5 Mc/sec. The plus sign indicates the ordinary component and the minus sign the extraordinary component. The absorption of the extraordinary wave is thus greater than that of the ordinary wave.

In many applications the frequency of the incident wave is much greater than the critical frequency in the region of interest and μ can be taken as unity. Then the formula for attenuation S can be conveniently expressed in the form

$$\frac{dS}{dh} = 4.6 \times 10^4 \frac{n\nu}{\nu^2 + (\omega \pm \omega_H)^2} \text{ dB/km} .$$

The absorption technique has been used in several variations. The simplest form consists of a fixed frequency transmitter on the ground and a receiver on the rocket, the signal strength being telemetered back to the ground. No distinction is made between the two components so that, in effect, the ordinary component alone is measured. An independent knowledge of the electron collision frequency is required. Rawer and Argence[8] made use of terrestrial broadcast stations and used a swept-frequency receiver on the rocket. They obtained a daytime profile of electron density from 70 to 87 km by this technique. Bowhill and Mechtly[9] used a 512 cps transmitter in nighttime measurements and showed the very sharp lower boundary of the D layer at about 75 km. They were able to measure electron densities down to about 100 cm^{-3}.

<u>2.2.1.4 Differential Absorption</u>. The more sophisticated version of the absorption technique distinguishes the two components and by measuring them separately obtain electron collision frequency as well as electron density. The differential absorption technique has been described by Seddon.[10] Using 7.74 Mc/sec in a midday flight differential absorption was first detected at 88 km and measured up to 96 km.

The differential absorption experiment can generally be combined with the Faraday rotation experiment using no additional equipment.

2.2.2 Probe Techniques.

2.2.2.1 Resonance. The plasma frequency in the vicinity of a rocket is determined in an ingenious manner in the rf resonance probe based on laboratory studies of Takayama, et al.,[11] and used on sounding rockets by Hirao.[12] It has been found that the dc current to an electrode to which is applied an rf signal reaches a peak when the frequency equals the plasma frequency. The theory of the technique is not yet available but it appears to give values of electron density in agreement with the formula

$$n = 1.24 \times 10^{-8} f^2$$

in cm^{-3} when f is in cps.

The effect of electron collisions is to damp the resonance peak and in practice damping prevents the use of the technique in the daytime D region below 95 km. It is also found that no resonance peak can be obtained with low electron densities (as in the nighttime E layer) even though no appreciable damping is present. The technique is thus of rather limited use in the lower ionosphere.

2.2.2.2 Capacity. A measurement of the capacity of an electrode system immersed in a plasma gives the dielectric constant and hence electron density of the medium. Numerically

$$C = C_o(1 - 8.1 \times 10^7 n/f^2)$$

where C_o is the capacity in free space

n is the electron density (cm^{-3})

f is the frequency of the applied signal (cps).

Jackson and Kane[13] used a dipole antenna as the electrode system and a frequency of 7.75 Mc/sec and actually measured the amount of capacity to be added to maintain resonance at the antenna. This is $C - C_o = C_o(8.1 \times 10^7 n/f^2) = C_o\ 1.35 \times 10^{-6} n$, at the frequency used. It was found that the electron density indicated by the probe was less than the values obtained simultaneously by the CW propagation (dispersive Doppler) technique. The discrepancy is attributed to the formation of an ion sheath around the antenna.

The effect of electron collision frequency is to damp the resonance of the antennas. In general the frequency must be much greater than the gyro-frequency, the plasma resonance frequency and the electron collision frequency if the simple form of the experiment is to be used. In the D region these requirements produce a small capacity change which becomes very difficult to measure. Sayers has proposed an ingenious variation of the technique in which the capacity is "modulated" by varying the dc potential of the electrode system. This system has not yet been proved in a rocket flight but, using a frequency of 40 Mc/sec it is expected to be able to measure electron densities of 100 cm^{-3} in the D region.

<u>2.2.2.3 Impedance</u>. The standing-wave impedance probe described by Haycock and Baker[14] measures the electron density in terms of the standing-wave pattern in a tapped transmission line between a 12 Mc/sec oscillator and a dipole antenna. A sawtooth generator is used to determine the effect of

vehicle potential on the measurements. Ulwick et al[15] have described the use of this probe. The calculation of electron density, using magneto-ionic theory, has been indicated by Pfister et al[16] for an earlier version of the probe in which separate measurements were made at 3.0 Mc/sec and 7.2 Mc/sec.

The limitations of this technique are essentially the same as the capacity probes and their use is limited to altitudes above about 85 km.

2.2.2.4 Langmuir Probe. The use of a probe in studying plasmas was originally put on a sound theoretical basis by Langmuir and his colleagues.[17] Experimentally an electrode is inserted into the plasma and the current to it determined as a function of the potential of the electrode. From the resulting current-voltage characteristic the electron energy distribution (electron temperature) and the electron density are obtained.

The theory of the probe is based on an extension of the kinetic theory of gases to a plasma. For retarding potentials, the current density to the electrode is independent of the shape of the electrode and has a value given by

$$j = j_o \exp(eV/kT)$$

where the random current density j_o is given by

$$j_o = ne\,\bar{v}/4$$

The mean velocity of the electrons $\bar{v}$ is obtained from kinetic theory

$$\bar{v} = \sqrt{(8kT/\pi m)}$$

The temperature is first obtained from the slope of a plot of log j against V and j_o from the value at space potential whence the electron density may be computed.

The Langmuir probe has been more important in the measurement of electron temperature rather than electron density and its use for this purpose has been described by Spencer et al.[18]

The use of the Langmuir probe is limited to altitudes above about 85 km. Below that height the simple theory indicated above is invalid for two reasons: (1) electron collisions with the neutral gas particles cannot be neglected, and (2) negative ions may be present in significant numbers.

There appears to be no theoretical lower limit to the electron density that can be measured and it appears practical to measure as low as 10 cm^{-3}.

The application of the Langmuir probe to the ionosphere is not completely understood, however. It is found, for example, that the electron random current density is smaller than that calculated from the simple theory by a factor approaching an order of magnitude. This factor is believed to be an effect of the earth's magnetic field and has not yet been explained.

2.2.2.5 dc Probe. The current to an electrode at constant potential is, by Langmuir probe theory, proportional to electron density. There should also be some dependence on electron temperature but using a nose tip electrode on a rocket payload at a small positive potential it has been found that the current is very closely proportional to electron density over a wide height range including both D and E regions.[19] No complete theory for the probe operated

in this way has yet been given. The profiles shown in Figure 2 were obtained using this technique.

The dc probe has almost no limit to its height resolution and has been very effective in showing up sporadic E-layers and other fine structure of the electron density profile. It also has the considerable advantage of almost entirely eliminating data reduction; the telemetered data from the rocket is immediately available as an electron density profile.

2.2.2.6 Ion Trap. A suitably biassed grid in front of the electrode allows the separate measurement of electron and positive ion current as functions of retarding potential. This is of great significance in the lower ionosphere, particularly in the D region, where it cannot be assumed that the negative ion density is negligible, a point of importance in theories of the region.

The ion trap may be spherical as used by Gringauz and his co-workers[20,21] and by Sagalyn et al[22] or it may be planar. Examples of the planar type have been described by Bourdeau and Donley,[23] McKibbin[24] and Hinterreger.[25] In some of these ion traps an additional grid is biassed to suppress photoemission from the surface of the collecting electrode.

The spherical and planar ion traps are equivalent in theory and the selection of one type against another is largely made on practical grounds. The spherical trap is independent of aspect while the planar trap requires a separate knowledge of aspect angle. The planar traps are generally easier to construct, particularly when more than one grid is used.

The ion trap, either planar or spherical, may be mounted on the body of the vehicle or at the end of a boom. The latter is the preferred mounting as it allows the trap to be placed outside the ion sheath of the vehicle and the potential of the outer grid may be swept through space potential.

The use of ion traps in the D region requires careful study. The relatively high gas density and high velocity of the vehicle produce an aerodynamic disturbance which may profoundly affect the collection of ions and electrons. It is expected, however, that these problems will be overcome and the trap used in the D region.

<u>2.2.2.7 Conductivity</u>. Ion density can be obtained immediately from a measurement of electrical conductivity σ. The kinetic theory of ionized gases leads to the simple formula

$$\sigma = \frac{1}{2} \frac{ne^2}{m\nu}$$

where ν is the ion-neutral collision frequency (which may be obtained with adequate accuracy by assuming an atmospheric model such as the 1959 ARDC atmosphere).

The technique used below the ionosphere where free electrons are negligible is to measure the current flowing between concentric cylinders (known as a Gerdien condenser) when a small potential is applied and the air is moving through the condenser at sufficient velocity. If the velocity is not sufficient or the potential too great the ion density of the air is reduced and ultimately all ions are removed from the condenser. In this case the device becomes an ion counter and the current is given by the rate at which ions enter; thus

$$i = ne\ v\ A$$

where v is the air velocity and A the cross sectional area. This is exactly the formula for the current to an ion trap and indicates the equivalence of the two techniques. The Gerdien condenser can be regarded as the low atmosphere equivalent of the Langmuir probe since in each the current flowing to the electrode depends on the potential. The technique has been widely used on the ground, carried on airplanes and on balloons up to altitudes of 30 km. The same technique has been used with some success by Bourdeau et al,[26] who mounted two Gerdien condensers (one each for positive and negative ions) on the nose of a rocket and measured polar conductivities up to 80 km.

2.3 COMPARISON OF TECHNIQUES

The dispersive Doppler technique has proved its value for altitudes above about 80 km and for electron densities greater than 10^3 cm^{-3} in many daytime flights in the lower ionosphere. The experiment is soundly based on magneto-ionic theory. In common with other propagation techniques, it fails under certain conditions. In a rapidly varying environment such as occurs during auroral disturbances a change of electron concentration at any point along the propagation path affects the received signal and cannot be distinguished from a spatial variation at the rocket. The propagation experiments are also subject to interference from other transmitters and from signals reflected by the ionospheric layers.

A probe technique must necessarily be used when the environment is changing rapidly but may also be used effectively under quiet conditions. The probe techniques are more susceptible to interference arising from the vehicle itself than are the propagation techniques. Potentially important are the following

sources of disturbance: (1) escaping gas and surface outgassing, tending to dilute the plasma, (2) ionization by rf breakdown, increasing the electron density, (3) absorption of rf energy, increasing the electron temperature, (4) rectification at the antennas, modifying the vehicle potential, (5) photoemission from the surface of the vehicle and the probe, and (6) magnetic fields (including geomagnetic field) modifying the motion of electrons.

These sources of disturbance can be made negligible in the design of the experiment or a correction made to the theory of the probe. The most important effects, in practice, are those caused, under certain conditions, by on-board transmitters. It has been found that rf breakdown at the antennas (as indicated by a reduction in radiated power) resulted in suppression of the current in a Langmuir probe experiment.[27] This was avoided in later flights by reducing the transmitted power, at least in the D region. This points up the importance of testing the payload in an environmental chamber at pressures which simulate the atmosphere up to 90 km.

The selection of a probe technique or combination of techniques must ultimately be made on the basis of detailed consideration of the application. First, however, they may be considered by region in which the technique is used. The techniques quoted in Section 3 are assigned potential use in either the D region or the E region in Table 2. These have been considered separately because of the basic difference between the two regions. Three techniques are indicated as "possible" as their ability to measure low electron densities in the D region has yet to be demonstrated, although there is no theoretical restriction on their use.

TABLE 2

D AND E REGION TECHNIQUES FOR ELECTRON DENSITY

	D Region	E Region
(a) Propagation Techniques		
Dispersive Doppler	Possible	Yes
Faraday Rotation	Yes	Yes
Absorption	Yes	No
Differential Absorption	Yes	No
(b) Probe Techniques		
Resonance	No	Yes
Capacity	Possible	Yes
Impedance	Possible	Yes
Langmuir Probe	No	Yes
dc Probe	Yes	Yes
Ion Trap	Possible	Yes

Three propagation techniques and two probe techniques have demonstrated the ability to obtain a D region profile and of these, one propagation experiment and both probe techniques are also useful in the E region. When propagation techniques are excluded as must be the case in a rapidly changing ionosphere the techniques suitable for both D and E region are dc probe and the ion trap. The capacity and impedance probes are considered as possibilities for measurement in the combined regions though some development of the techniques is necessary before the adaptation to the gun probe can be considered.

The simplest technique from the point of view of instrumental complexity is undoubtedly the dc probe, consisting only of an electrode and an electrometer. The addition of a sweep generator between the electrode and the electrometer converts the instrument to a Langmuir probe.

The use of a Langmuir probe in studying plasmas is performed experimentally by inserting an electrode into the plasma and determining the current to it as a function of the potential of the electrode. From the resulting current-voltage characteristic the electron energy distribution and the electron density may be obtained if certain restrictions are adhered to.

(1) The probe dimensions must be small in comparison to significant changes in potential over the space it occupies.

(2) The current drawn by the probe must not disturb the plasma.

(3) There must be no production of electrons by impact, photoemission, etc., at the probe surface.

(4) Contact potential differences must be constant.

(5) Radio-frequency fields must be absent (because of the possibility of exciting plasma oscillations).

(6) The geometry of the probe arrangement must be clearly defined.

Within the limitations imposed by these criteria, the Langmuir probe has been developed for firing from a cannon and has proved an elegant and powerful tool for the study of low pressure discharges.

2.4 MEASUREMENT OF ELECTRON ENERGY

The most important property of electrons in the ionosphere, after number density, is their energy. When the electrons are in thermal equilibrium among themselves (but not necessarily in equilibrium with ions or neutral particles) the energy distribution is Maxwellian and can be specified by a temperature T.

Several techniques are available for measurement of electron temperature, all based on Langmuir probe theory and all capable of measuring the complete energy distribution. The distribution function can be expressed in terms of the probe current density j and voltage V in the following way, due to Druyvesteyn[28]

$$F(v_e) = \frac{1}{n}\frac{dn}{dV_e} = \frac{(8m)^{1/2}}{e^{3/2}} V^{1/2} \frac{d^2j}{dV^2}$$

The second derivative can be obtained by graphical analysis of the current-voltage curve but several electronic techniques are now available which allow the function to be obtained more conveniently and more accurately. These methods have recently been discussed generally by Branner et al.[29]

A simple method has been used by Takayama et al,[11] in which a small ac signal is superimposed on the sweep voltage producing a change in the current averaged with respect to the ac signal. If i_o is the current into the

probe at a given retarding potential V_o then the addition of an ac signal $V\cos\omega t$, where $|V|<|V_o|$, increases the current from i_o to a new value

$$i = i_o J_o (ieV/kT)$$

where $J_o(ieV/kT)$ is the zeroth order Bessel function for a pure imaginary argument. Some value of the function are given in Table 3.

TABLE 3

Values of $J_o(ieV/kT)$

eV/kT	0	1	2	3	4
$J_o(ieV/kT)$	1.000	1.266	2.280	4.881	11.302

A measurement of the ratio of the current with and without the ac signal present gives the value of J_o and, since V is known, leads immediately to the electron temperature T. The frequency of the ac signal may be in the audio frequency or radio frequency range but in any case should be no greater than 10 percent of the plasma frequency in order to avoid resonance effects.

A more elaborate probe of this type has been used by Boyd and Willmore[30] on the satellite Ariel. Two small ac signals having amplitudes of 50 to 100 mV and frequencies of 500 cps and 3 kc/sec are added to the normal sweep voltage of the probe. The curvature of the current-voltage characteristic produces components of current to the probe having frequencies equal to the sum and difference of the two applied ac signals. The components at the higher frequency (3.5 kc/sec) is selected by a tuned amplifier and the depth of modulation measured. This gives the ratio of the first and second

derivatives of the curve which, for the case of a Maxwellian distribution is equal to the electron energy (in volts, if practical units are used.)

If it can safely be assumed that the electron energy distribution is Maxwellian the output of the Boyd instrument is available as an analog output of electron temperature and the information can be transmitted in a small bandwidth, limited only by the resolution desired. Transmission of the complete energy distribution requires a correspondingly larger bandwidth.

The use of the Langmuir probe for temperature measurements is limited, as noted earlier for electron density measurements, to altitudes greater than about 85 km. It is conceivable that the technique could be extended to lower altitudes but, at present, no adequate theoretical basis exists for use of the technique in the main part of the D region. The electron energy can be obtained, although less directly, from the collision frequency of electrons with neutral particles using the theoretical expression,

$$\nu = \frac{4}{3} n\pi\sigma^2 \left(\frac{8kT}{\pi m}\right)^{\frac{1}{2}}$$

in which n is the number density and $\pi\sigma^2$ the cross section of the neutral particles and $(8kT/\pi m)^{\frac{1}{2}}$ is the electron mean velocity. Unfortunately the collision cross-section is not known well enough nor the composition above 85 km to allow an accurate test of the expression. It follows, however, that the collision frequency for electrons with neutral particles should be in constant ratio with the collision frequency for neutral particles with neutral particles, given for the 1959 ARDC Model Atmosphere in Table 1. Comparison with measurements of electron collision frequency

obtained by Kane[31] shows that the ratio $\nu_{electron-neutral}/\nu_{neutral-neutral}$ has the value of 10 with an uncertainty of about 50 percent (i.e. that ratio lies within the range 5 to 15). It seems that until more observational material becomes available a useful model of the electron collision frequency is obtained by multiplying the neutral particle collision frequency given in Table 1 by 10.

An important point concerning the use of electron collision frequency in absorption calculations has also been noted by Kane. The value of ν in the preceding discussion is strictly the collision frequency of electrons having equal energy. In the ionosphere the electrons almost certainly have a Maxwellian energy distribution and the Appleton-Hartree magneto-ionic theory must be modified to allow for this. It appears from the work of Sen and Wyller,[32] for example, that the Appleton-Hartree theory can still be used with an effective collision frequency, ν_{AH}, equal to $1.5\nu_m$, where ν_m is the collision frequency of mono-energetic electrons. For the most accurate work, however, this approximation is not adequate and the generalized magneto-ionic theory must be used.

2.5 SUMMARY

The nature and application of the instrumented projectile excluded the use of propagation techniques though these are better developed both theoretically and in the practice. The probe techniques have come into use relatively recently with notable success in the E region but with only limited success in the D region. The two most promising probe techniques were considered to be the dc and Langmuir probes and the rf (capacity) probe. The

former was used in this system in preference to the rf probe for two main reasons:

(1) The potential value of the dc probe and Langmuir probe in the D region has been demonstrated in several rocket flights whereas the capacity probe has yet to be tried.

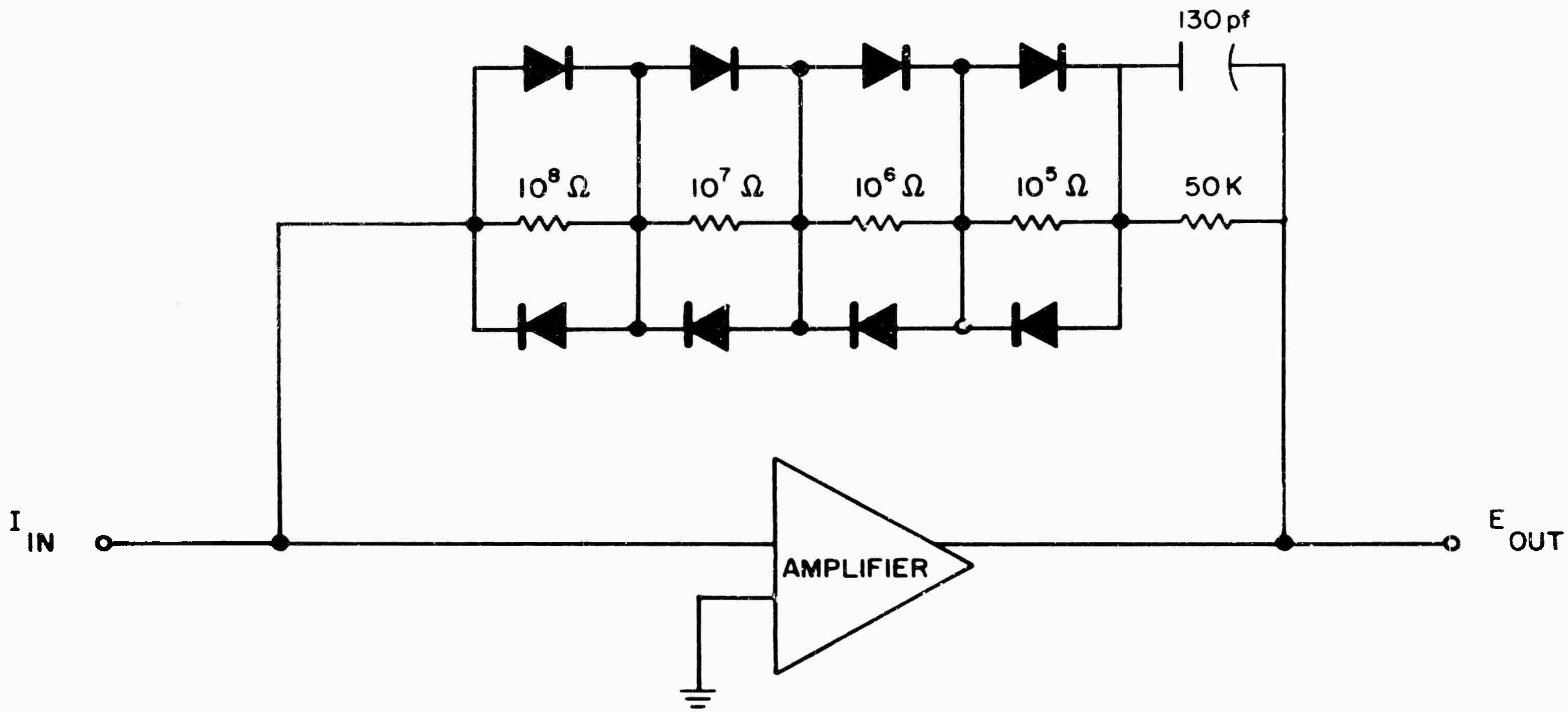
(2) The dc probe and Langmuir probe are instrumentally, rather simpler than the capacity probe and are more likely to be successfully adapted to the severe environment of the projectile.

SECTION 3

EQUIPMENT DESIGN

3.1 ELECTROMETER AMPLIFIER

Electronic circuits for both the dc probe and the Langmuir probe were developed for this program. It was necessary to measure ion and electron current over a wide dynamic range, starting at 10 electrons per cubic centimeter. For an electrode area of 100 cm^2, a current of 10 electrons/cm^3 corresponds to 10^{-9} amperes. An operational amplifier with a dynamic range of 5 decades was developed with a logarithmic feedback element. The feedback circuit is shown in Figure 3. This shows a number of diodes in series across a set of resistors. The theory of operation is that a minimum current of 10^{-9} amperes flowing in the feedback loop will cause voltage to be generated across the 10^9 ohm value resistor. As the input current increases, the voltage across the 10^9 ohm resistor increases and approaches the forward conduction point of the diode across it. The diode will limit the voltage across the resistor to approximately 0.5 volts. As additional current is placed across the feedback network, the voltage will now build up across the next resistor in line; the 10^8 ohm resistor. When the voltage across the 10^8 ohm resistor reaches 0.5 volts, the diode across it conducts and effectively shorts out the resistor. Each resistor in turn will become part of the feedback loop until the input current reaches 10^{-4} amperes. The output voltage at this point will equal 2.5 volts. In this manner, the output voltage will vary from 0 to 2.5 volts when the input current varies from 10^{-9} amperes to 10^{-4} amperes.



OIEC28-511H

Figure 3. Amplifier feedback loop.

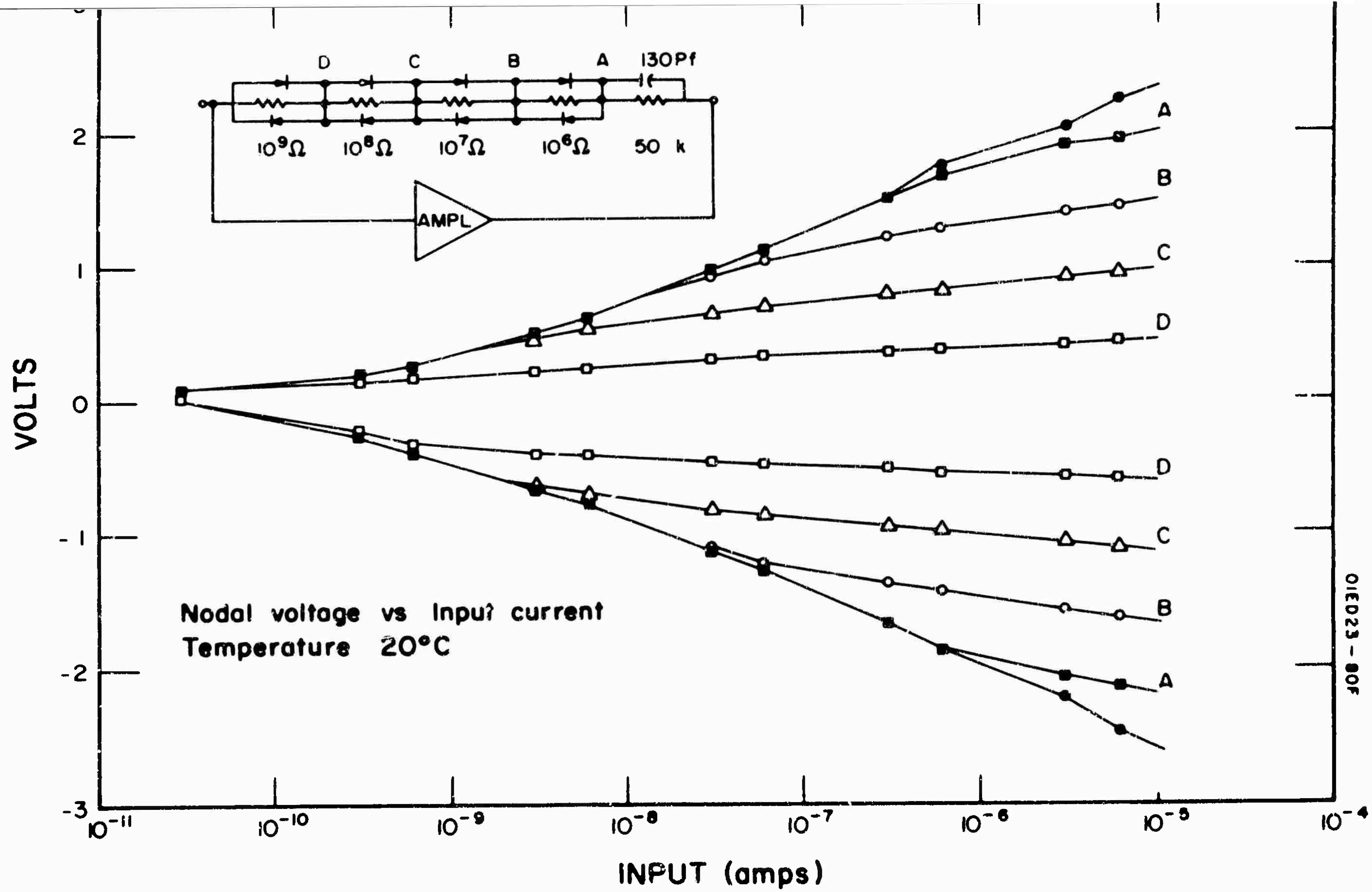
Figure 4 shows the clamping effect of the diodes. In this test the currents were varied from 10^{-11} amperes to 10^{-5} amperes with the output and points A, B, C, D monitored. Note the diode clamping is logarithmic rather than linear. This effect serves to enhance and smooth the logarithmic feature of the amplifier output voltage (E out). The curve remains logarithmic from approximately 10^{-10} amps to 10^{-5} amps. Above that value additional input current is impressed across the 50,000 ohm resistor and the output approaches a linear feedback characteristic.

The design of the amplifier follows an operational amplifier technique (Figure 5). The input transistors Q2A and Q2B differential amplifier transistors are preceded by emitter followers Q1A and Q1B. Transistors of extremely low current leakage are used in this front end to maintain a very low input leakage current. Typical differential input leakage current is approximately 10^{-11} amperes. The output of the differential amplifier is fed to a second differential amplifier stage for additional gain, and the output of stage Q3A and Q3B is fed to a single ended amplifier Q4. In order to maintain a low output impedance, the output of Q4 is fed into a complimentary emitter follower amplifier Q5 and Q6. The output of this is fed to a thermistor resistor network.

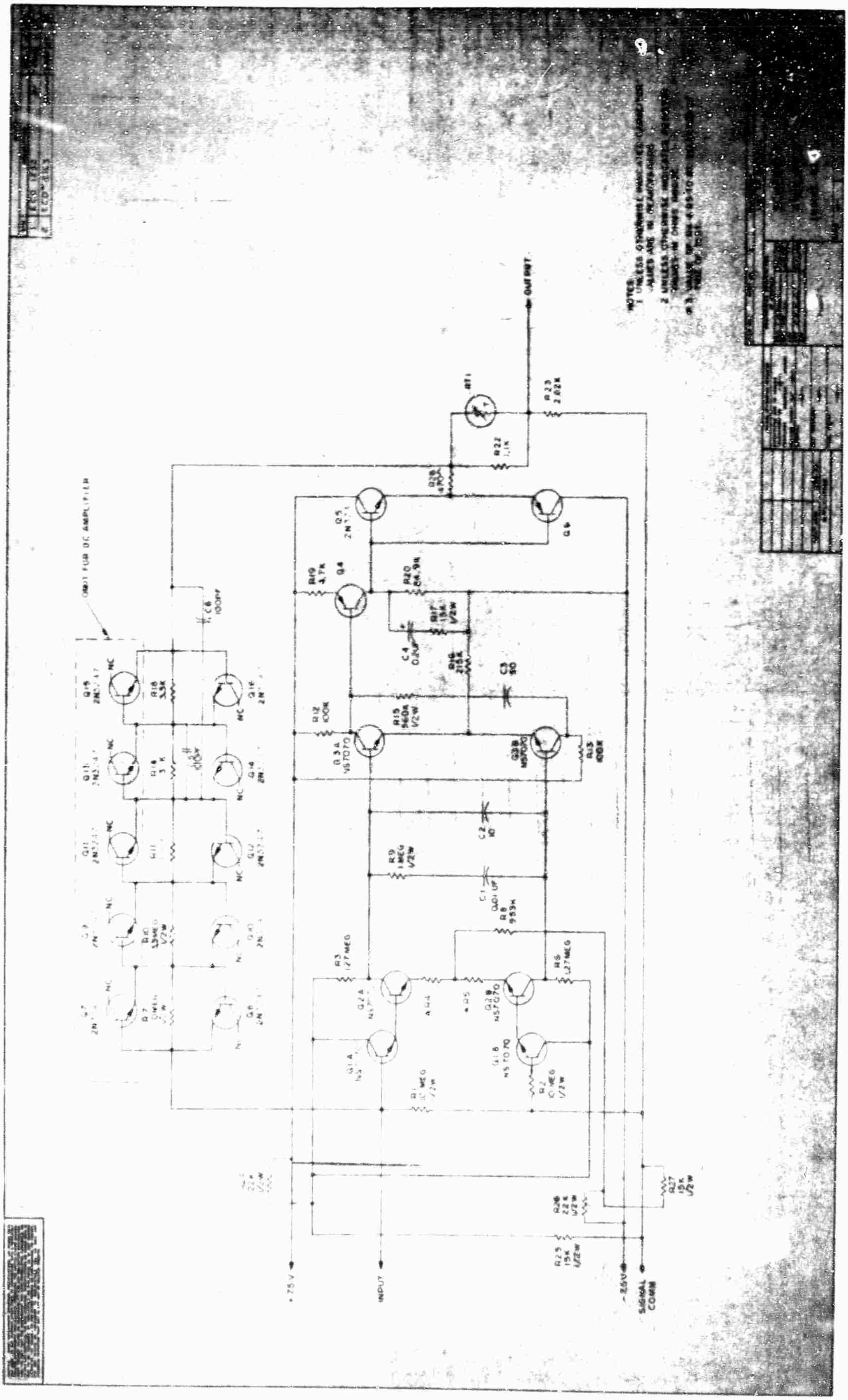
The following precautions were taken in order to limit drift in the amplifier:

(1) The transistors in the front end differential stages are matched pairs with each pair enclosed in a single case.

(2) Precision resistors are used wherever changes in resistance characteristics may cause drift.



igure 4. Amplifier feedback characteristics.



OUTPUT
INPUT
SIGNAL COMM
NOTES

(3) The dc open loop gain is large to make gain variations an insignificant portion of the drift.

The amplifier operates over the temperature range of 0 to +65°C for a full five decade current input with a drift of less than ±100 millivolts. This corresponds to an accuracy of greater than 1/4 decade. The closed loop amplifier frequency response is shown in Figure 6.

3.2 RAMP GENERATOR

The Langmuir probe (ac probe) consists of an electrometer amplifier plus a ramp generator to provide a saw-tooth ramp to the probe. (See Figure 7). The ramp generator which is placed in a series with the probe and the amplifier has an independent, isolated battery power supply. It generates a saw-tooth wave form that varies from minus 2.7 volts to plus 2.7 volts as shown in Figure 8. This has the effect of placing a variable voltage across the probe to measure electron and ion currents and allow for the measurement of electron temperature.

The ramp generator circuit is shown in Figure 9. It consists of Q2, a unijunction transistor oscillator, with a constant current source generated by Q1 for a linear saw-tooth wave form, and two emitter followers, Q3 and Q4, for low output impedance.

The linearity of the output saw-tooth wave form from the ramp generator circuit was measured using the system in Figure 10. The system operates in the following manner. The ramp generator output voltage varies from -2.5 to +2.5 volts. When the ramp voltage is -2.5 volts, it activates P-65 Amplifier

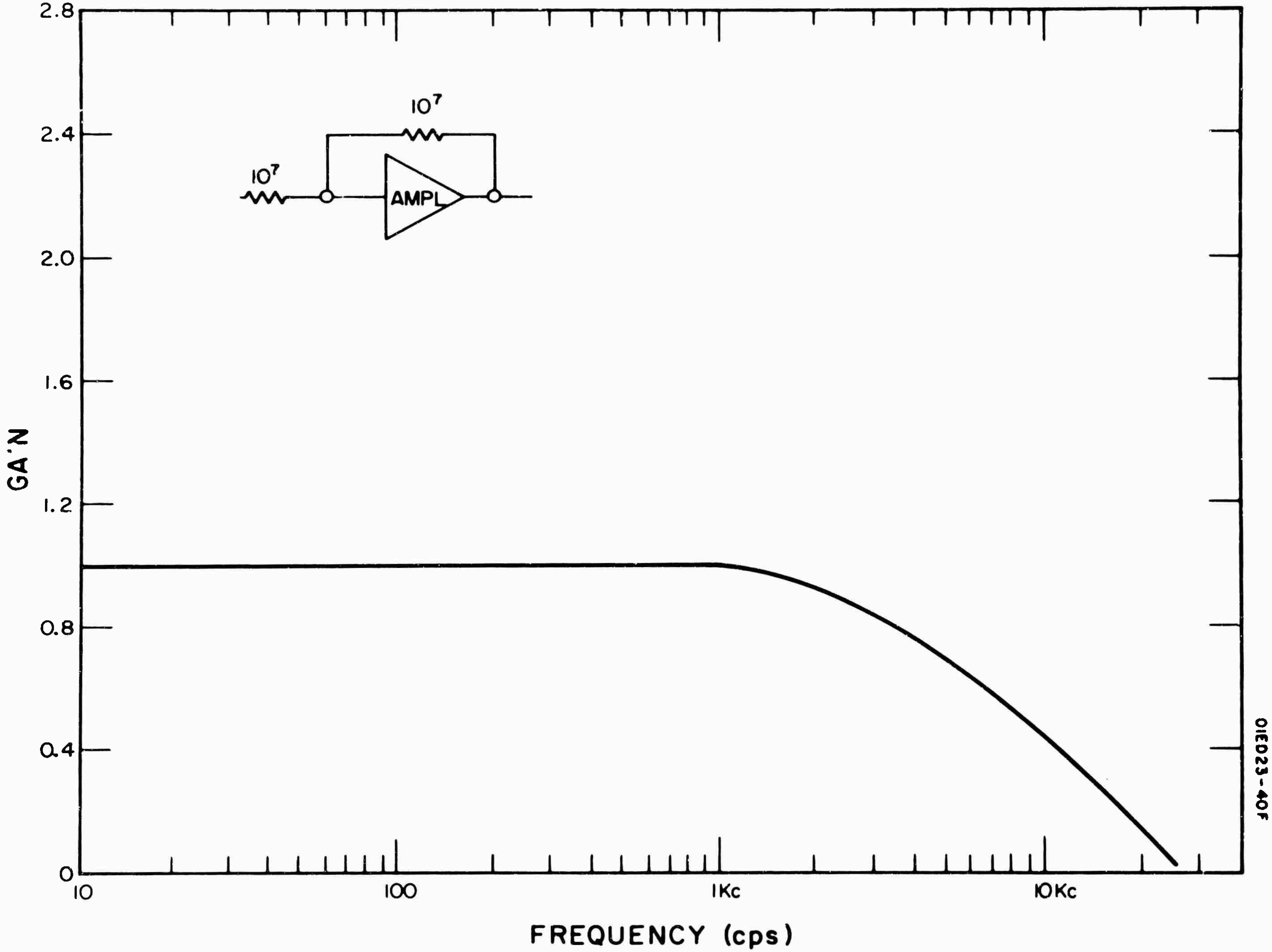


Figure 6. Amplifier gain characteristics.

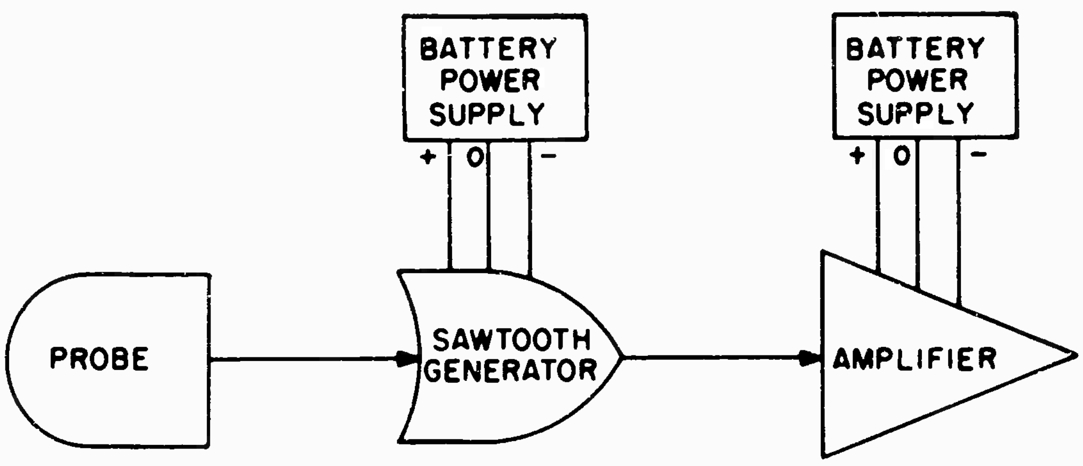


Figure 7. Langmuir probe electronics.

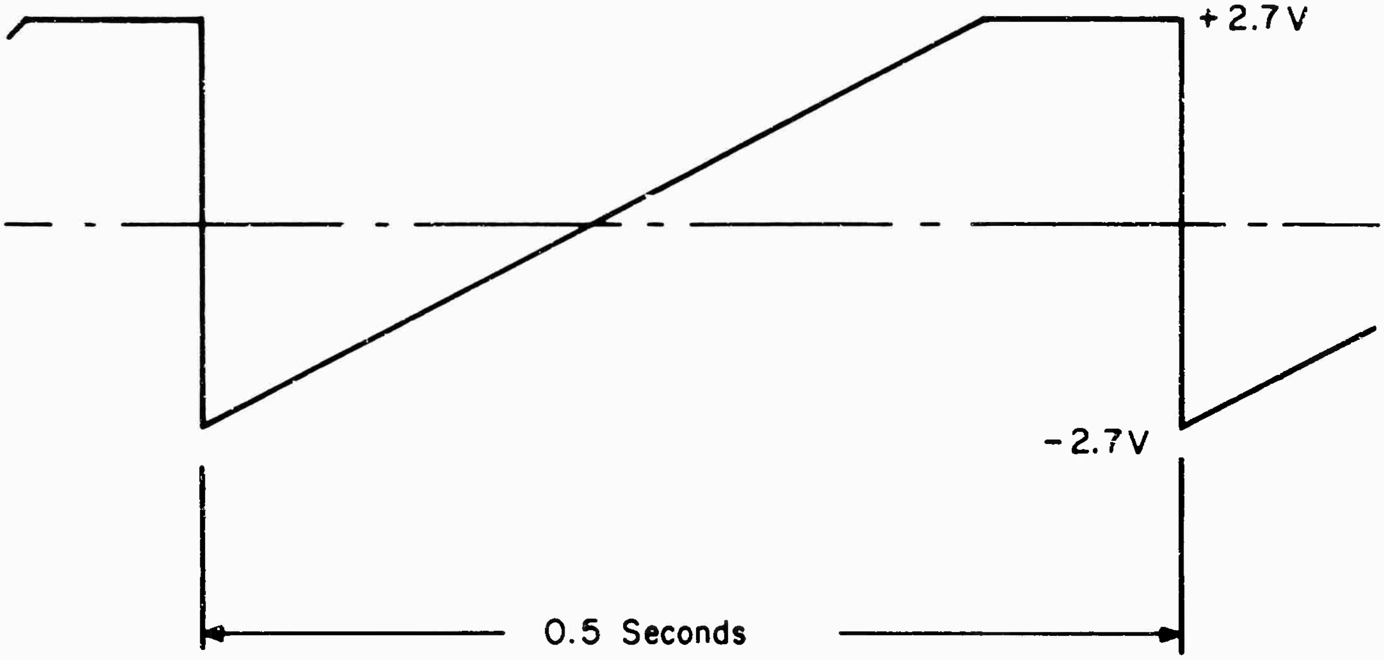


Figure 8. Sawtooth waveform.

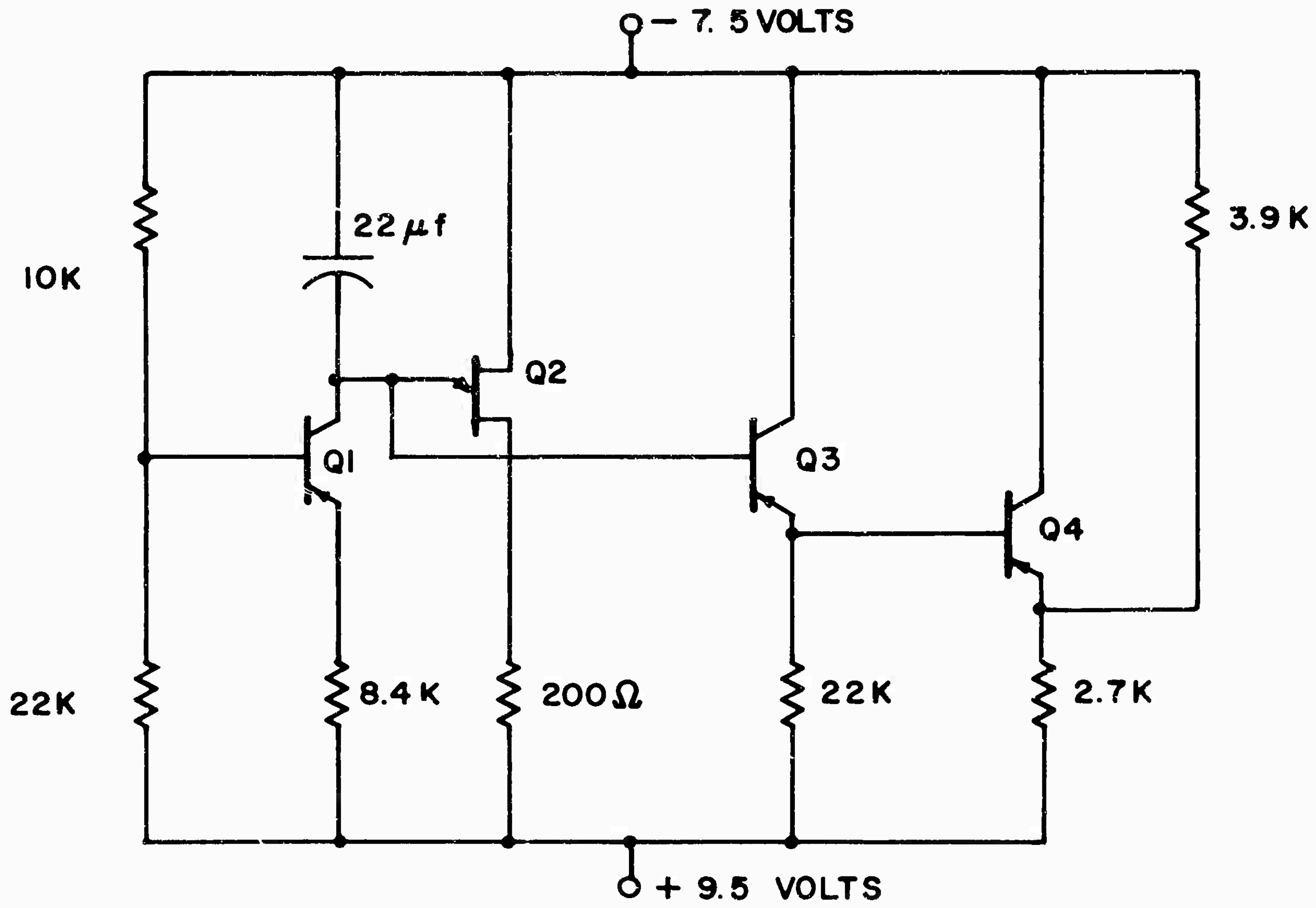


Figure 9. Sawtooth generator.

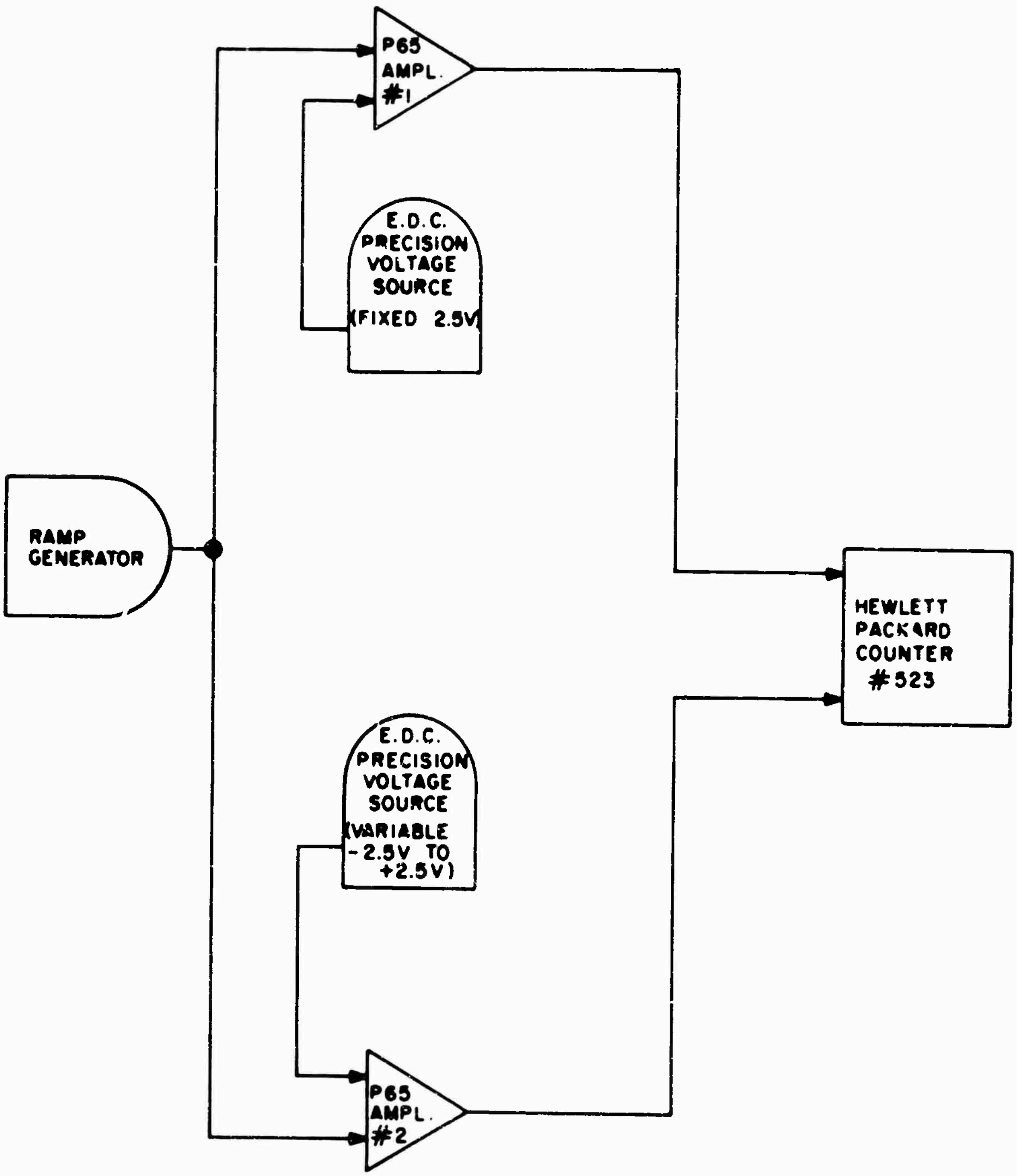


Figure 10. Sawtooth waveform measuring equipment.

No. 1 and a start pulse is sent to the Hewlett Packard Counter. The EDC variable precision voltage power supply is preset to any voltage. When the ramp generator output equals this voltage, P-65 Amplifier No. 2 sends a stop pulse to the Hewlett Packard Counter, and the time interval between the start and stop pulse is read on this counter. Figure 11 shows the curve obtained by varying the precision voltage source from -2.5 volts to +2.5 volts and measuring the different time intervals. As can be seen, the linearity of this curve is better than $\pm 1/4$ percent of full scale as measured from a straight line.

3.3 COMPONENT EVALUATION

Once the electronic amplifier and ramp generator circuits were established a program to obtain components rugged enough to withstand the severe mechanical environment was initiated. The selection of components was based on those components that had a small mass, a rugged construction, and were either all solid or capable of being made into a solid structure. For example, carbon composition resistors were selected for they are of solid mass. Transistors in TO5 cans were used. Prior to their use, the top of the transistor can was removed and the transistor was filled with a solid epoxy. Solid ceramic chip transistors were also used with no modification.

The components selected were tested in lots of a minimum of twelve units each. The units were mounted on glass epoxy boards 1.8 inches in diameter and encapsulated into cylinders. These cylinders were then mounted inside the shell of a 5-inch cannon, and the shell was fired into a block of lead. The acceleration from the cannon was in the order of 1000 G's. When the modules impacted the block of lead, they received a deceleration of up to 60,000 G's.

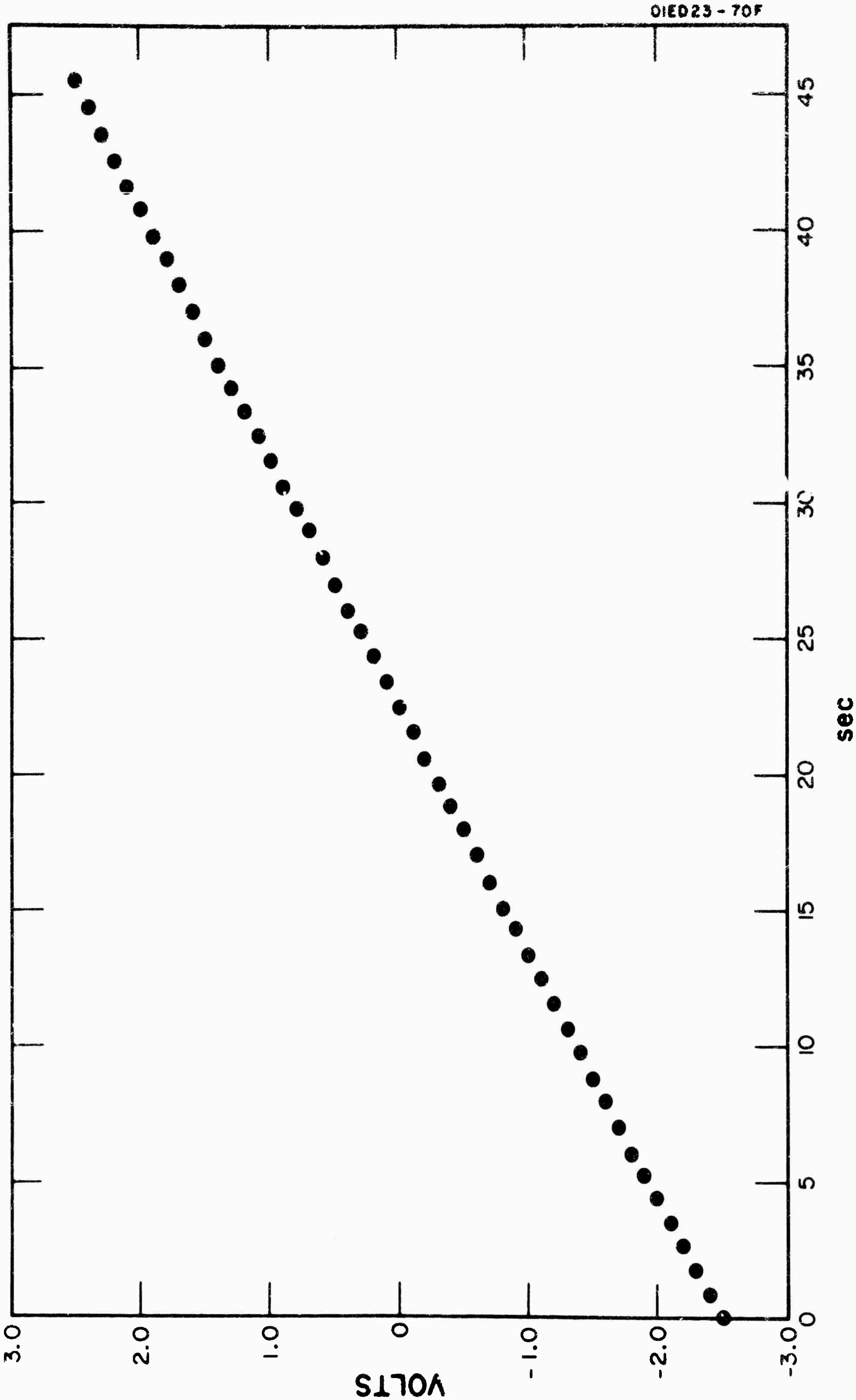


Figure 11. Linearity check.

Figure 12 shows a potted amplifier ready to be placed in the cannon shell for tests.

The modules were test ' a minimum of three times in this manner. If more than one of twelve components in each type tested failed to survive after three tests, the component type was eliminated from further use. Thus, by a careful test program and rigid acceptance procedures, a high confidence level was established in the development of the gun launched probe.

The following list is a tabulation of components fired and the test results.

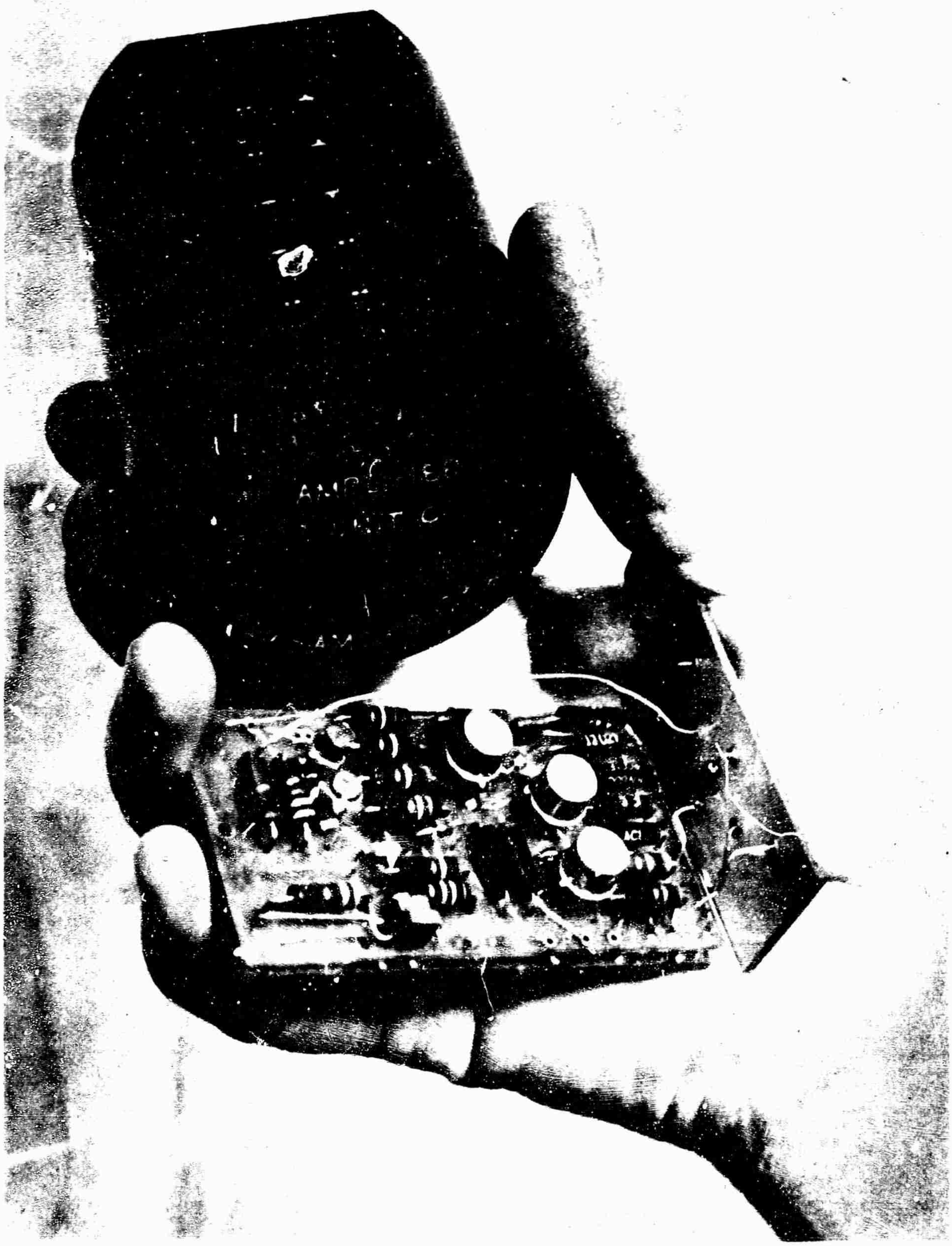


Figure 12. Potted amplifier.

ITEM	Hi G TEST NO.	QUANTITY	RESULTS
Motorola Unijunction 2N3480 Chip Transistor	2	3	All Satisfactory
TI UNI SJ993 TO-18 Potted	2	4	3 Satisfactory 1 Failed
Unitrode VZ807 7V Zener Diode	2	8	4 Satisfactory 4 Failed
North American Electronics 12V Zener Diode	2	9	6 Satisfactory 3 Failed
Components Inc. Minitan Capacitors			
Y102A 0.001uf at 20V	2	12	
S22 22uf at 15V	2	12	
L10 10uf at 20V	2	12	All Satisfactory
G106R 10uf at 15V	2	6	
G106 10uf at 15V	2	6	
National Semiconductor 2N3547 PNP Microtransistor	2	5	All Satisfactory
Motorola PNP Microtransistor	2	4	All Satisfactory
Fairchild μL930 Dual Gate Flat Pack	2	12	4 Satisfactory 8 Failed
Fairchild μL903 Gate TO-5	3 3	5 Potted 6 Unpotted	All Satisfactory 3 Satisfactory 3 Failed (all on same board)
Fairchild μA702 Amplifier TO-5	3	4 Potted by Mfg.	2 Satisfactory 2 Failed 1st Hi G Test
	3	8 Potted by GCA	7 Satisfactory 1 Broken in Lab. Accidentally
		11 Unpotted	All Satisfactory
Fairchild 2N3277 Field Effect Transistor	2	2 Units TO-18 Potted by GCA	All Satisfactory

TYPE	No. UNITS	No. TESTS	RESULTS
National Semiconductor NS700 Chip Transistor	6 Dual	3	All Satisfactory After Test 2. All breaking down at low voltage after Test 3.
Amelco 2N2453 Transistor	12 Dual Units	1	11 Failed
Sperry 2N2590 Transistor (case potted by GCA)	14	3	1 Failed on Test 2. All other satisfactory after Test 3.
Cont. Device 2N2480 Transistor	12 Dual	1	7 Halves Failed
Cont. Device 2N1711 Transistor	12	1	2 Failed
Sperry P21C312 NPN Transistor (case potted by GCA)	10	3	All Satisfactory
GE 2N490 Unijunction Transistor	6	1	All Failed
GE 2N490 Unijunction Transistor (case potted by GCA)	11	1	9 Failed
NS 7070 Transistor	3 Dual 1 Half	4	All Satisfactory
NS 7070 Transistor	10 Dual 3 Halves	3	All Satisfactory
Sperry 2N2602 Transistor (case potted by GCA)	6	3	All Satisfactory
Crystalonics PNP Transistor (case potted by GCA)	8	3	All Satisfactory
Crystalonics PNP Transistor (case potted by GCA)	10	2	All Satisfactory after Test 1. One Failed Test 2.

TYPE	No. UNITS	No. TESTS	RESULTS
GE 2N2040 Unijunction Transistor (case potted by GCA)	5	4	All Satisfactory after Test 1, one degraded after Test 2 but still operating. 4 units satisfactory after Test 4.
TI Unijunction Transistor (case potted by GCA) Uni 2N3480	9	1	5 Failed
Motorola MU970 Transistor (case potted)	9	3	All Satisfactory
GE 2N2646 Unijunction Transistor (case potted)	5	1	All Failed
GE 2N2647 Unijunction Transistor (case potted)	6	1	1 Failed
1 AC6.8 6.8V Zener Diode	9	1	4 Failed
AM308A Diode CAMO	10	1	All Failed
Veco Thermistors			
10 meg	6	4	5 Satisfactory 1 open after Test 2
8 K	6	4	All Satisfactory after Test 2. After 3, 2 units reading 2-3x hi in value.
Fenwall Thermistors			
10 meg	6	4	All Satisfactory
8 K	6	4	All Satisfactory
Allen-Bradley 1/2 watt 10^9-2 Carbon Comp. Resistors	14	3	All Satisfactory
Resistance Products Corp. Resistors 10^9-2 Carbon Film	12	3	1 Failed Test 3 (opened)

TYPE	NO. UNITS	NO. UNITS	RESULTS
Electra RN60D 1K Resistors	14	3	All Satisfactory
IRC 100 Meg 10% 1/2 watt carbon Resistors	12	1	All Satisfactory
Metohm RN60C 470π Resistors	6	1	1 Open
Metohm RN55C 470π Resistors	6	1	4 Open
ACI 4.99K RN60C Resistors	24	3	All Satisfactory
Allen Bradley 1/8 watt 5% carbon comp. 220-2	10	2	All Satisfactory
100M	10	2	All Satisfactory
Sprague 1550 15uf at 20V Capacitors	10	1	3 Failed
Vitramon VK30CW (miniature ceramic) 0.001 uf Capacitors	6	3	All Satisfactory
0.001 uf	6	3	All Satisfactory
ITT 2uf Capacitor	12	1	All Failed
Corning CY20C Capacitor	12	3	All Satisfactory
Dervax 0.01 uf Capacitor	12	3	All Satisfactory
Minitan Corp. Capacitors			
0.22uf at 35V	12	1	All Satisfactory
0.22 uf at 20V	12	3	All Satisfactory
22uf at 10V	12	3	3 Failed Test 1 1 Failed Test 2
Dervax Miniature Electrolytic Capacitors 25uf at 15V	12	3	All Satisfactory

TYPE	NO. UNITS	NO. TESTS	RESULTS
Transistor Corp. Capacitors TES 2-75C1N1 2uf at 75V	12	3	One Failed Test 3
Gould 100 mch Batteries (Mercury)	9	3	All Satisfactory
Gould 100 mch Batteries (Mercury)	3	1	1 Failed
Mallory RM400 Batteries (Mercury)	14	3	4 Failed Test 3
Mallory RM675 8V Battery Pack	2	1	Both Failed
Eveready E400	6	1	All Satisfactory
Eveready Battery Pack Potted in Burs. case by mfg.	3	3	
#1-6V	1	2	#1 Failed Test 2
#2-6.7V	1	1	#2 Failed Test 1
#3-7.8V	1	3	#3 Satisfactory After Test 3
Ray-O-Vac (potted by mfg.) 6V Battery Pack	6	3	All Satisfactory
Varo Micro-Circuits			
#8102 Nor Gate	1	1	Failed
#8107 Flip Flop	1	1	Failed
ac Amplifier	1	2	Failed Test 2
GCA Built Circuits			
dc Amp 10^{-9} to 10^{-4} amps	1	4	Satisfactory
dc Amp 10^{-8} to 10^{-3} amps	1	4	Satisfactory
ac Amp 10^{-8} to 10^{-3} amps	1	2	Satisfactory after Test 1, Failed Test 2
Ramp Generator			
Unijunction Model	1	2	Satisfactory
Flip Flop Model	1	2	Satisfactory After Test 1, Failed Test 2

3.4 COMPONENT PREPARATION

Component preparation and potting of assemblies was a very important operation in producing reliable assemblies. Components having voids as part of its makeup such as transistors in TO-5 cans were modified by opening the cans and filling the voids with an epoxy resin.

This operation is quite important since transistor junctions exposed to air will degrade rapidly if not isolated from the gases in the atmosphere.

The process used to encapsulate the transistor after the cases were opened is as follows:

(1) Immediately after the cases are cut open, the transistor chip is coated with Dow Corning Type 644 junction coating resin. A thoroughly cleaned glass rod and a <u>minimum</u> amount of resin is used. The resin is applied to the clear area and is allowed to flow over the junction.

(2) The transistor is baked at 150°C for 4 to 6 hours.

(3) Equal parts (by weight) of silica and Epon 815 are mixed together and baked 15 minutes at 150°F (65.5°C).

(4) The mixture is reweighed and 8 to 12 parts per hundred weight of resin of DTA or 10 to 14 parts per hundred weight of TETA are added. The smallest practical amount of resin is used to reduce effects of exothermic reaction and mixed thoroughly.

(5) The mixture is evacuated for approximately 1 to 3 minutes after the mixture collapses at 30 inches of mercury.

(6) A minimum amount of resin is used to form a thin coating over the chip and leads.

(7) After the coating is completely cured, a second batch of the above mixture is used to fill the transistor case.

3.5 ASSEMBLY AND POTTING PROCEDURE

The final unit is assembled on printed circuit cards in either a flat board or cordwood construction. This circuit is placed in a metal mold and filled with a resin containing hollow silica micro balloons that gives the resin a very low specific gravity (0.72) and a low viscosity. After filling, a final casting dimension tolerance of ±.002 inches is maintained. This potting procedure is as follows:

(1) A small batch of 1090S1 is mixed and evacuated for approximately 2 to 3 minutes after mix collapses at 30 inches of mercury.

(2) A thin coating is poured slowly over the amplifiers being careful that all components, especially the transistor, are completely surrounded with the potting material. The mixture is evacuated for 2 to 3 minutes at 30 inches of mercury and allowed to cure at room temperature for 8 to 12 hours until the resin is hardened.

(3) The <u>coated amplifier</u> is assembled with the ramp generator together with an end plate such that the top terminal board and end plate are 90^{o} to one another. A number is scribed on top terminal board and end plate so that units can be identified after potting. A "G" switch is installed at this time.

(4) 1090S1 slugs and blocks are banded to assembled unit to fill empty spaces. This lowers the volatile mass and reduces the exothermic reaction to a minimum.

(5) Prior to installing assembly in mold the mold is cleaned and washed with trichlorethylene and sprayed with a teflon coating for easy release.

(6) A batch of 1090S1 is mixed to half fill the mold and evacuated 2 to 3 minutes after the mix collapses.

(7) The mixture is poured very slowly until mold is half filled, taking caution not to entrap air bubbles.

(8) The mold is evacuated again for approximately 2 minutes at 30 inches of mercury until bubble activity decreases substantially.

(9) The mold is allowed to cure at room temperature for 2 to 3 hours, until the resin begins to harden. At this stage the chemical change (exotherm) is 80 to 90 percent completed.

(10) The above process is repeated filling mold to 1/2 inch above amplifiers. The final unit is allowed to cure 16 to 20 hours before removing from the mold.

(11) After curing, the unit is faced off to the desired length.

SECTION 4

FLIGHT TESTS

Three Martlet II projectiles were fired from the Harp 16-inch gun (Figure 13) at Barbados, West Indies, during the May - June, 1965 test series. These projectiles were instrumented with the BRL 1,750 sec telemetry system and GCA probe sensors. The rounds were BRUTUS (dc probe) and IRE and JANUS (ac Langmuir probes). Figure 14 shows a projectile prior to firing.

The ion and electron density measurement payloads consisted of a 1,750 Mc/sec FM transmitter, two subcarrier oscillators, a commutator, the Langmuir probe, a flush resonant cavity antenna, battery pack, and acceleration switch, an aspect magnetometer to measure spin rate and altitude, and sensors to measure on-board temperatures.

The signals were received from the rounds BRUTUS and IRE for 240 and 233 seconds respectively, with some breaks in the received signal record. A continuous signal was received from round JANUS for 210 seconds, with no breaks in the record. The signals from all rounds ceased on descent prior to impact probably due to cutoff of the transmitter from aerodynamic heating defects. Angle tracking data were obtained with the modified GMD tracking unit during two of the three Martlet II firings. The tracking unit was inoperative during the third firing due to a circuit breaker failure.

4.1 BRUTUS

BRUTUS contained a dc probe using a nose tip electrode at a fixed potential of +2.7 volts. Excellent data was received ontinuously from T+3

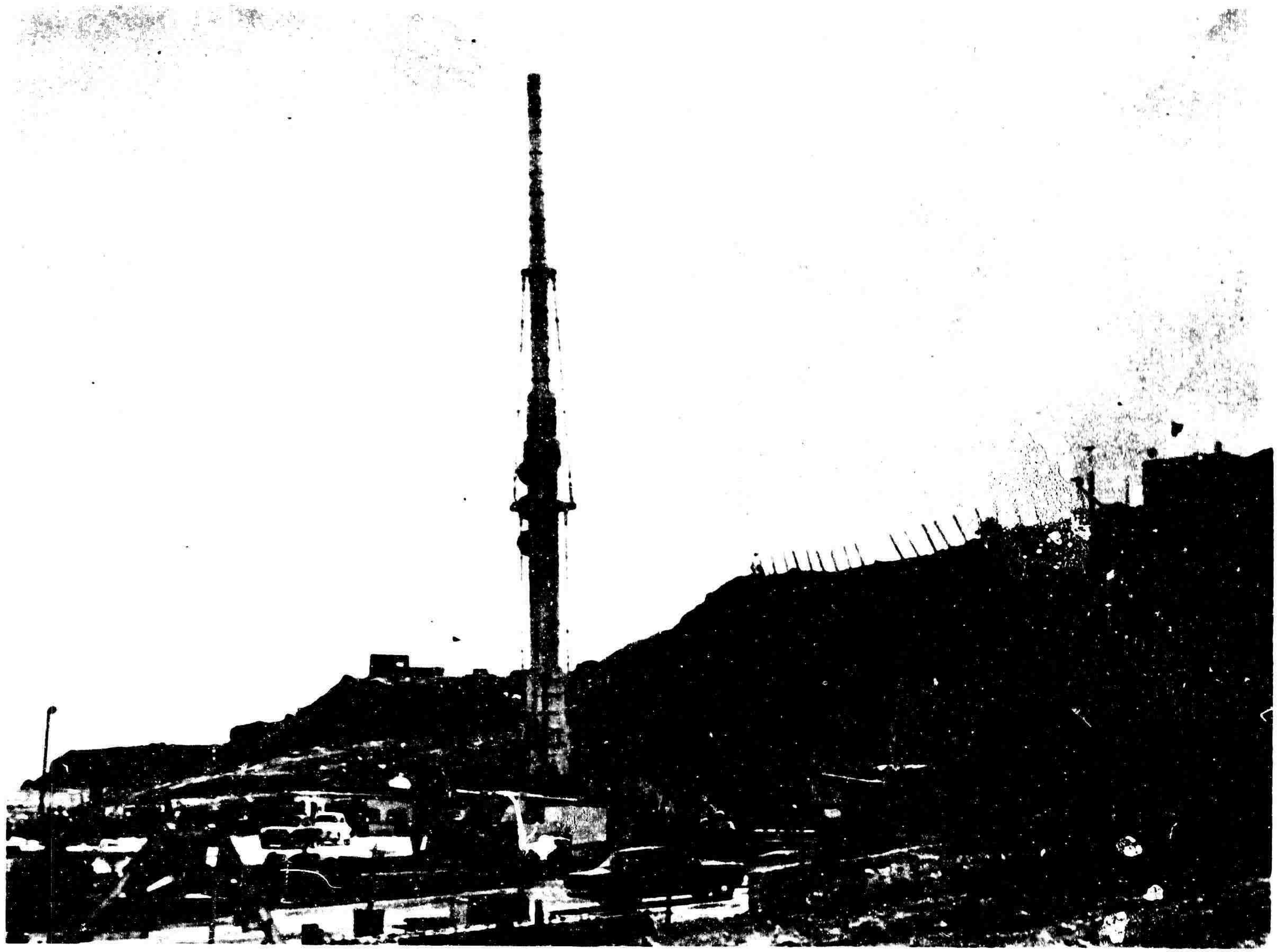


Figure 13. 16-inch gun.

Figure 14. Projectile prior to firing.

seconds to T+115 seconds, intermittently from T+195 seconds to T+218 seconds, and then continuously from T+222 seconds to T+240 seconds. The maximum altitude of the projectile was 120 km. The variation of probe current with time for this shot is shown in Figure 15. This shows the current decreasing in the first 50 seconds of the flight. The reason for the presence of this current is not understood. It may be a leakage current caused by contamination of the insulator or possibly by moisture absorbed by the insulator. In either case it is presumed that the leakage would continue to decay exponentially at a rate given by the interval T+18 to T+33 seconds. This extrapolated leakage current is then subtracted from the observed current to give the current due to collection of ambient electrons by the probe. The current, corrected for leakage, is plotted in Figure 16 against altitude. The leakage correction is negligible above 70 km. The figure also shows a profile obtained using a similar probe on a Nike Apache rocket. The rocket probe current has been increased by a factor of six to allow for the difference in surface area of the two probes. The agreement between the two profiles is excellent between 58 km and 92 km. The disagreement of the lowest altitude is attributed to the large error introduced by the leakage current in the case of the gun probe. Above 92 km the gun probe current is lower than that of the rocket. This can probably be interpreted as an effect of outgassing of the projectile. The accumulation of gas around the electrode is made possible by the low velocity of the projectile near apogee. The somewhat larger values of probe current on descent support this view (the rate of outgassing presumably decreases with time). It has been observed that deliberate release of gas from a rocket payload reduces the current to a similar level. This problem could possibly be greatly reduced on

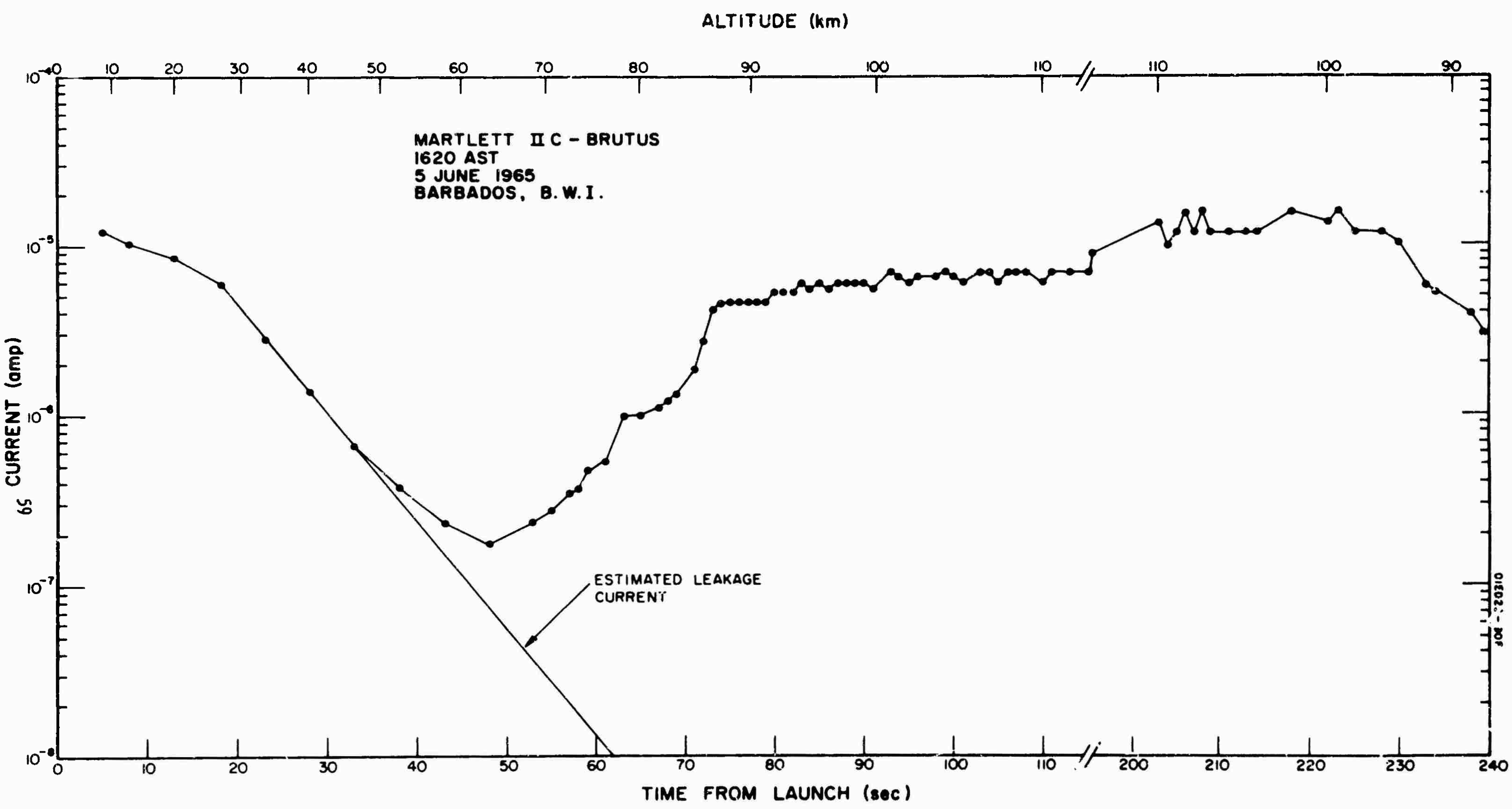


Figure 15. Gun probe flight.

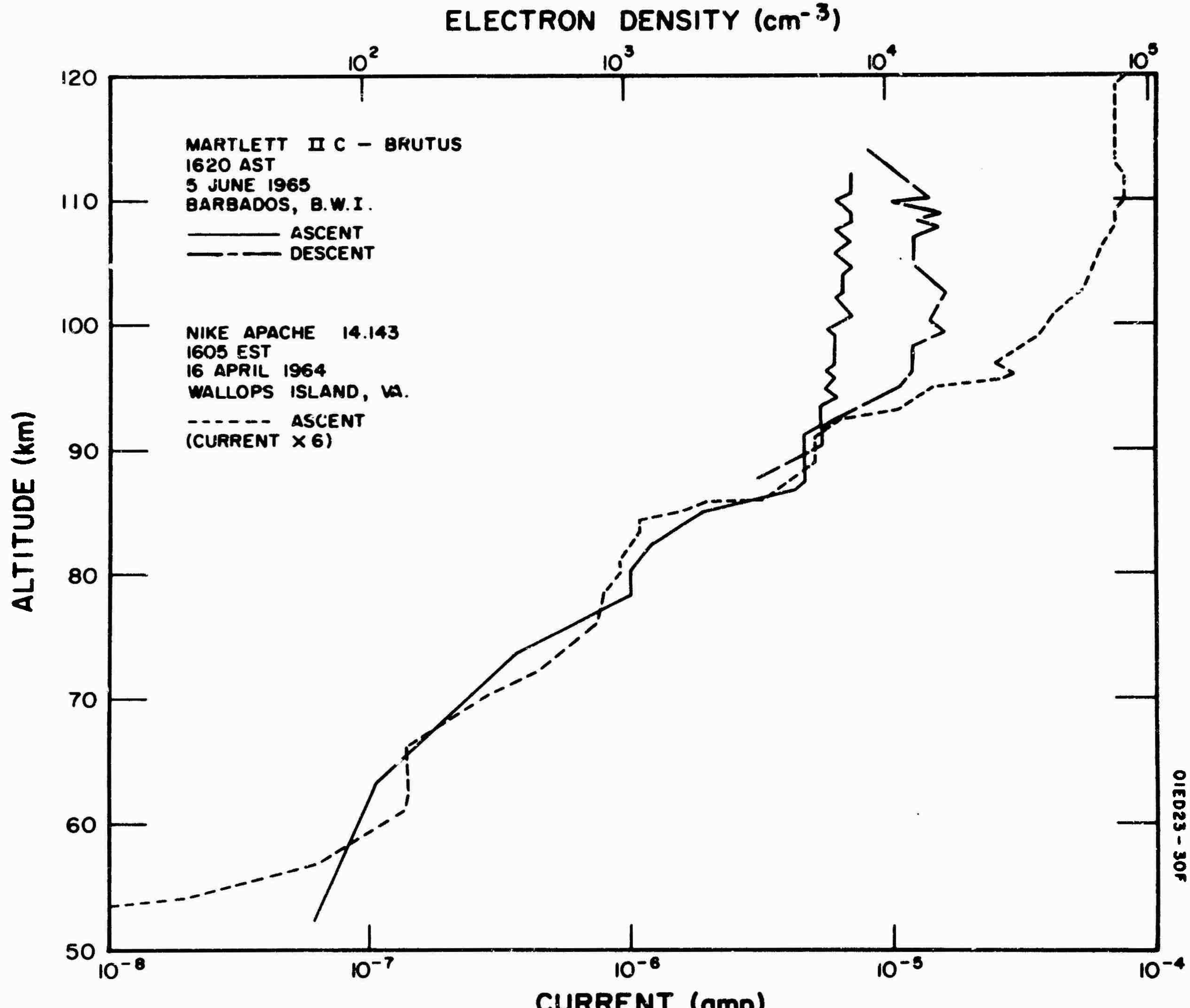


Figure 16. Flight characteristics.

future gun shots by decreasing the elevation level of the gun at launch. This will increase the total velocity of the projectile near apogee by adding an appreciable horizontal component.

4.2 IRE AND JANUS

Both shots use the same type nose tip electrode as BRUTUS but in both cases the normal Langmuir probe mode of operation was used. The potential of the electrode was swept between -2.7 volt and +2.7 volts. The sweep duration was 0.5 second and was repeated twice per second. The analog voltage representing probe current was transmitted over two channels of telemetry. One channel was continuous information the other was a sampling rate of six samples per second or three samples per sweep. The commutator was not synchronized with the sweep generator. These flights were marred by instrumentation difficulties and no reliable scientific data was obtained.

A good telemetry signal was received on shot IRE from T+1 second to T+75 seconds, then at T+92 seconds for six seconds and T+109 seconds for four seconds; finally, a 6-second period from T+226 seconds. The data was confined to the commutated channel. This shot shows the same leakage effect in the early part of the flight as was observed on BRUTUS. The leakage decays more rapidly however, and minimum current is observed at T+33 seconds. After about T+65 seconds the effect of the sweeping voltage can be recognized showing that the sweep circuit was operating at that time. However prior to that time no variation in current corresponding to the variation of potential can be detected. This throws some doubt on the interpretation of the current in the first 30 seconds as being leakage.

The telemetry signal from shot JANUS was good from T+5 seconds to T+108 seconds. Again only the commutated channel gave data. The probe current was zero for the whole duration of the telemetry signal.

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

The performance of the probes flown in the HARP firings in Barbados, British West Indies, in May and June 1965, demonstrates the feasibility of electron density profile measurements with a gun probe. There is generally good agreement in the 65 to 110 killometer region with previous probe profiles obtained using the rocket launch.

The instruments used to perform this measurement were the dc probe and the Langmuir probe. The dc probe and the Langmuir probe has proved to be a very valuable instrument for performing measurements in the ionosphere when fired from a cannon. These probes are very simple in construction requiring a minimum of electronics and very simple mechanical nose tip construction. The greatest advantage of the instruments as they have been developed is the ability to resolve fine structure in the ionosphere.

Recommendations for future work would include a sub-miniaturization of the instrument to allow its launch from a 5-inch gun. It is felt that this probe could be reduced in size from its present 2 1/2-inch diameter, 3-inch height to a 1 1/2-inch diameter cylinder by 1/2-inch height. This reduction in size would allow for parachute launches as well as standard type launches from the 5-inch gun.

An investigation of the high leakage phenomena occurring for the first thirty seconds to one minute after launch should be pursued to determine whether these high leakage effects are atmospheric, mechanical, electronic,

or a combination of all three.

A correlation of the effects of high acceleration for varying periods of time should be performed. For example, the acceleration-time characteristics vary from 50,000 g's for approximately 3 milliseconds for the 7-inch gun to 10,000 g's for up to 100 milliseconds for the 16-inch gun. At the present time sufficient data is not available to correlate these effects on electronic components and packaging techniques.

REFERENCES

1. Schaeffer, E. J. and M. H. Nichols, "Neutral Composition Obtained for a Rocket-borne Mass Spectrometer," COSPAR Symposium, Warsaw, June 1963.

2. Nicolet, M., and A. C. Aikin, "The Formation of the D Region of the Ionosphere," J. Geophys. Res. 1469-1483, 1960.

3. Smith, L. G., "Rocket Measurements of Electron Density and Temperature in the Nighttime Ionosphere," GCA Technical Report No. 62-1-N, January 1962.

4. Smith, L. G., "Measurements of Electron Density Profile in the Nighttime E. Region," GCA Technical Report No. 63-22-N, June 1963.

5. Seddon, J. C., "Propagation Measurements in the Ionosphere with the Aid of Rockets," J. Geophys. Res. 58, 323-335, 1953.

6. Prenatt, R. E., "Ionospheric Structure Above Fort Churchill, Canada, From Faraday Rotation Measurements," ARS J., 763-765, 1960.

7. Aikin, A. C., J. A. Kane and J. Troim, "An Interpretation of a Rocket Measurement of Electron Density in the Lower Ionosphere," COSPAR, Warsae, June 1963.

8. Rawer, K. and E. Argence, "Information Obtained by Passive Radio Frequency Spectrometers in Rockets," Space Research II, ed. Van der Hulst, et al., 1220-1214, 1961.

9. Bowhill, S. A. and E. A. Mechtly, "An Ionosphere Electron Density Experiment Particularly Suited for Small Rockets," Space Research II, ed. Van der Hulst, et al., 1208-1214, 1961.

10. Seddon, J. C., "Differential Absorption in the D and Lower E Regions," J. Geophys. Res. 63, 209-216, 1958.

11. Takayama, K., H. Ikegami and S. Miyazaki, "Plasma Resonance in a Radio-Frequency Probe," Phys. Rev. Let. 5, 238-240, (1960).

12. Miyazaki, S., K. Hirao, Y. Aono, K. Takayama, K. Ikegami and T. Ichimiya, "Resonance Probe - A New Method for Measuring Electron Density and Temperature in the Ionosphere," Rep. Ion and Sp. Res. Jap., 14, 148-159, 1960. (No. 2)

13. Jackson, J. E. and J. A. Kane, "Performance of an RF Impedance Probe in the Ionosphere," J. Geophys. Res., 2209-2210, 1960.

14. Haycock, O. C. and K. D. Baker, "Measuring Antenna Impedance in the Ionosphere," Electronics, 34, 88-92, 1961.

15. Ulwick, J. C., W. Pfister, R. P. Vancour, R. T. Bettinger, O. C. Haycock and K. D. Baker, "Firing of an Astrobee 200 Rocket with a Multiple Ionospheric Experiment," Proc. IRE, 50, 2272-2286, 1962.

16. Pfister, W., J. C. Ulwick and R. P. Vancour, "Some Results of Direct Probing of the Ionosphere," J. Geophys. Res., 66, 1293-1297, 1961.

17. Langmuir, I. and H. M. Mott-Smith, "Studies of Electric Discharges In Gases at Low Pressures," General Electric Review 27, 449-455, 538-548, 616-623, 762-771, 810-820, 1924.

18. Spencer, N. W., L. H. Brace and G. R. Carignan, "Electron Temperature Evidence for Nonthermal Equilibrium in the Ionosphere," J. Geophys. Res. 67, 157-175, 1962.

19. Smith, L. G., "A DC Probe for Rocket Measurements in the Ionosphere," GCA Technical Report No. 63-19-N, June 1963.

20. Gringauz, K. I., V. V. Bezrukikh and V. D. Ozerov, "Results of Measurements of Positive Ion Concentrations in the Ionosphere by Means of Ion Traps on the Third Soviet Earth Satellite," Artificial Earth Satellites, No. 6, Moscow, 1961.

21. Gringauz, K. I. and M. Kh. Zeiikman, "Measurement of the Concentration of Positive Ions Along the Orbit of the Artificial Earth Satellite," Uspekhi Fiz. Nauk., 63, 239-252, 1957.

22. Sagalyn, R. C., M. Smiddy and J. Wisnia, "Measurement and Interpretation of Ion Density Distributions in the Daytime F Regions," J. Geophys. Rev. 68, 199-211, 1963.

23. Bourdeau, R. E. and J. L. Donley, "Explorer VIII Satellite Measurements in the Upper Atmosphere," NASA X-615-63-165, August 1963. (To be published in Proc. Roy. Soc.)

24. McKibbin, D. D., "A Direct Measurement of Charge Density in the F2 Region," IRE Transactions on Instrumentation, pp. 96-99, December 1962.

25. Hinteregger, H. E., "Combined Retarding Potential Analysis of Photoelectrons and Environmental Charged Particles up to 234 km," Space Research ed. Bijl. North-Holland Publishing Co., Amsterdam, 1960. pp. 304-327.

26. Bourdeau, R. E., E. C. Whipple and J. F. Clark, "Analytic and Experimental Electrical Conductivity Between the Stratosphere and the Ionosphere," J. Geophys. Res. 64, 1363-1370, 1959.

27. Smith, L. G., "Electron Density in the Ionosphere," GCA Technical Report No. 63-23-N, July 1963.

28. Druyvesteyn, M. J., Z. Physik. 64, 781-798, 1930.

29. Branner, G. R., E. M. Frair and G. Medicus, "Automatic Plotting Device for the Second Derivative of Langmuir Probe Curves," Rev. Sci. Inst. 34, 231-237, 1963.

30. Boyd, R. L. F. and A. P. Willmore, "A Method of Studying the Energy Distributions of Ionospheric Ions and Electrons," Space Research III, 1168-1173, ed. Pfister.

31. Kane, J. A., "Re-evaluation of Ionospheric Electron Densities and Collision Frequencies Devices from Rocket Measurements of Refractive Index and Attenuation," JATP, 23, 338-347, 1962.

32. Sen, H. K., and A. A. Wyller, "On the Generalization of the Appleton-Hartree Magneto-Ionic Formulas," J. Geophys. Res., 65, 3931-3950, 1960.

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) GCA Corporation GCA Technology Division Bedford, Massachusetts	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

HIGH ALTITUDE GUN PROBES

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report

5. AUTHOR(S) (Last name, first name, initial)

6. REPORT DATE September 1965	7a. TOTAL NO. OF PAGES 70	7b. NO. OF REFS 32

8a. CONTRACT OR GRANT NO. DA-19-020-AMC-00292(R) b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) GCA Technical Report 65-15-G 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. AVAILABILITY/LIMITATION NOTICES

Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY U.S. Army Ballistic Research Laboratories Aberdeen Proving Ground, Maryland

13. ABSTRACT

This final report describes a program to develop an instrument capable of measuring electron density in the 50 to 160 kilometer altitude region and capable of surviving a 60,000 "G" shock encountered during launch from a cannon. This report is in two parts: The first describes various techniques and instruments capable of measuring electron density in this altitude region. The second section describes the design techniques as well as flight results from these probes. Both dc and ac Langmuir probes were chosen as the best instruments for fulfilling the system requirements.

DD FORM 1 JAN 64 1473

Unclassified
Security Classification

Unclassified
Security Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Ionosphere Gun probe Langmuir probe High accelleration Electron density						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
_______________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
_______________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
_______________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.